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MEMBER OF THE ASSOCIATION OF MUNICIPAL AND COUNTY ENGINEERS, ETC.;
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PREFATORY NOTE TO THE SECOND EDITION.

FOR some time past the first edition of this work has been out of print. This edition has been thoroughly revised, and much new matter added. The size of the book has been increased by 87 pages, in spite of the deletion of obsolete material, so as to include as far as possible some account of the changes that have been effected during the past seven years.

With the increasing adoption of self-propelled vehicles the subject of road-making and maintenance has acquired special importance. The conditions of traffic have altered in a remarkable manner as regards both kind and quantity; and better construction of macadamised roads has become imperative in order to withstand the new traffic and at the same time to resist the formation of dust and mud. The latter point has received special attention, and it is hoped that the information contained in the chapter that has been added on this important subject may help to suggest ways in which the experience gained in other districts may advantageously be applied in cases of difficulty.

T. A.

August 1907.

PREFACE.

THIS treatise is divided into two parts. The first relates to the making and the maintaining of Macadamised Roads, while the second part deals with Carriageways and Footpaths.

Although much has been written on the subject of making and maintaining macadamised roads, the recent introduction of mechanical appliances for quarrying, manufacturing, and consolidating the metalling has led to important changes on the older methods, whereby more expeditious, effective, and economical work has been rendered possible. The effect of the transfer of the management of the highways to the County Councils by the Local Government Acts has afforded scope for road maintenance on a larger scale than has hitherto been practised in this country.

The information here given, which treats of all matters relating to the systematic making and repairing of roads and streets, is for the most part the result of experience of the practical work of constructing roads and their subsequent maintenance, extending over a considerable number of years. The methods of carrying out the work and the cost of each operation are given in detail, and, it is hoped, are now brought together in a useful form.

In the second part, all the recognised descriptions of material used in the paving of carriageways and footways, and the latest methods of construction adopted in the principal cities and towns of the kingdom, are described. The cost of forming pavements and the comparative wear are also given in detail. The congestion of pedestrian and vehicular traffic in the larger towns, and the means of obviating the delays inseparable from the present state of matters, are noticed at some length. The benefits likely to result from the construction of subways are also described in a concise manner, while other matters of general importance receive due and adequate notice.

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ROAD MAKING AND MAINTENANCE

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ROAD MAKING AND MAINTENANCE.

HISTORICAL SKETCH.

Road Making.—Tredgold's definition of the profession of the Civil Engineer, which was adopted by the 'Institution of Civil Engineers' in their charter—viz., "The art of directing the great sources of power in nature for the use and convenience of man"—illustrates very forcibly the importance of road making as a branch of engineering practice.

The construction of roads or artificial ways is one of the first steps taken, with the spread of civilization, in opening up a country for the accommodation of travellers and the carriage of commodities.

Road makers may be looked upon as pioneers in the material advancement of a nation and in influencing society, the good condition in which roads are maintained being a fair indication of the progress or prosperity of any age or people.

The natural resources and manufactures of a country can only be developed by communication between towns and rural districts, or, in other words, "The road is so necessary an instrument of social well-being, that in every new colony it is one of the first things thought of. . . . The new country, as well as the old, can only be effectually opened up, as the common phrase is, by roads, and until these are made it is virtually closed."* The evolution of the modern road can only be adequately understood by reference to the practice of this interesting subject, from the time when the making of the great military roads of the Romans was carried out to the present time, authentic descriptions of which are recorded. It will be necessary, therefore, previous to detailing the different processes from the inception to the completion of roads and streets as now constructed, to review concisely the history of the subject, which extends over a period of 2200 years.

Roman Roads.—The Romans learned the art of making paved roads from the Carthaginians, and the highways constructed by them were regarded as of vital importance for conquest and the maintenance of their Empire, while they were admirable models of engineering skill.

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* Smiles' *Lives of the Engineers*, vol. i.

One of the oldest, and probably the most important of these paved military roads, called the 'Appian Way,' was commenced by Appius Claudius while holding the office of censor, in 312 B.C. Twenty-nine great military roads centred in Rome, many of which were carried in different directions to the extreme limits of the vast Empire, connecting the Capitol and the principal cities and strategic points.

These lines of communication, for a distance of 50 miles from Rome, were decorated on either side with temples and other superb edifices. Buildings were erected at regular distances alongside these roads at the public expense, and used as lodging-houses for changing horses to suit the wants of the couriers, and for the requirements of the army; mansions were also erected at intervals of from 30 to 36 miles for the accommodation of the soldiers.

Roman roads are remarkable for preserving a straight line from point to point regardless of obstacles, which by a slight detour could have been avoided. They were carried over marshes, lakes, ravines, and mountains, and have, by their bold inception, duration and stability, excited astonishment and admiration in all ages. The 'Appian Way' was not only the earliest military road, but the best constructed; and Statius, the poet, designates it as the Queen of Roads in his time. It extended to 360 miles; the portion from Rome to Capua, a distance of 142 Italian miles, was constructed during the censorship of Claudius. The remaining portion, extending in a south-easterly direction to Brundusium (now Brindisi), appears to have been carried out from time to time as the Romans conquered the states to the south. Julius Cæsar spent considerable sums of money on this road, and in all probability completed it to Brundusium. The mode of constructing this great military road was as follows:—

Two parallel trenches were excavated at a distance of about 40 feet apart to mark the width of the road, and also the direction which it was intended to follow. This at once gave the location of the road, and showed the nature of the subsoil, from which the level of the foundations was determined; all loose soil was removed, and replaced where necessary with suitable material, consolidated by ramming until a solid foundation was obtained for the support of the road materials.

This, in general, appears to have been composed of four layers of material having a total thickness of 3 feet, local stone being used when available, though at times the material was brought from a considerable distance. The lowest layer, or *statumen*, was formed of two courses of flat stones laid in mortar; over this was laid the *rudus*, or rubble, well beaten; then the third layer, called the *nucleus*, a sort of *beaton*, was spread, being composed of coarse gravel and lime, used hot, and on which was bedded the *summa crusta*.

When the road was carried over marshy ground, a framework of carpentry was provided, called '*contignata pavimenta*,' and the frame itself *contignationes*.

The joists or sleepers were termed *coaxationes* or *cassationes*, and were made of an oak called esculus, because it was not liable to warp or shrink. To protect the timber from the effect of the lime mixed with the other materials, it was covered with a bed of rushes or reeds, and sometimes straw. On this stratum of reeds or straw was laid the *statumen* or foundation.

The second bed was made of broken stones mixed with lime, which Isidore calls *rudus*. When this material was composed of stones freshly broken, it was called *rudus novum*, and quicklime was added in the proportion of one of lime to three of stone. But when the material came from old buildings, it was called *rudus redivivum*, and then an additional portion of lime was used, two parts to five, and the work termed *ruderationem*; the rammer or beater was employed to strengthen, equalize, and smooth it. This composition, whether formed of gravel or *débris*, was 9 inches in thickness after it had been thoroughly rammed.

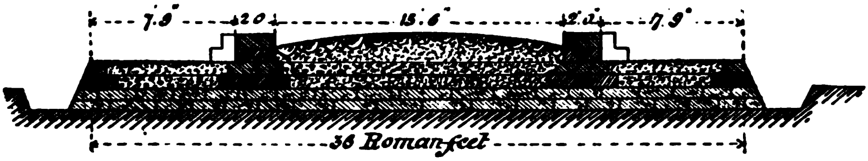

FIG. 1.—Cross-section of Roman road ('Appian Way').

Over this *tarras* or *ruderation*, a cement was laid for the third bed, which was composed of bricks, potsherds, or broken tiles mixed with lime, in the proportion of one of lime to three of brick. This was spread over the *ruderation* in a thin layer to receive the fourth bed or paving, consisting of polygonal blocks jointed with the greatest nicety, serving as a covering to the entire work, and was called in consequence *summam crustam*. The third bed, or nucleus, was the softest layer of the whole, and was interposed between the harder layers. The stones and cement which formed the road were not less than 6 inches in thickness, and the entire mass laid upon the framework of carpentry was 15 inches. Fig. 1 shows a cross-section of the 'Appian Way,' and typifies many of the other great military roads in the neighbourhood of Rome. The paved portion was about 16 feet wide, with margins on either side, separated by a curb 2 feet wide and 18 inches high, which served as seats for travellers. The margins were not paved with blocks, the finished surface being the gravel concrete; they were consequently at a lower level than and were only half the width of the centre portion.

The entire width of these military roads was from 36 to 40 Roman feet, the middle portion being for the infantry, while the margins were made use of by horses and carriages.

Of the other great military roads some were named after the Consuls and Emperors who had constructed them, such as the Flaminian and Domitian, while others were designated by the name of the province through which they passed, such as the Latian, Tiburtine, Campanian, and Praenestine ways.

Other roads constructed solely for civil purposes were connected with the great military ways and distinguished by the following names, *Via*, *Actus*, *Iter*, *Semita*, *Trames*, *Diverticulum*, *Divertium*, *Callais*, etc.*

Via answers to our common road; its breadth was 8 Roman feet, so that carriages could pass without collision.

Actus was a road for the passage of a single carriage; it derived its name from a measure used in surveying land, of which the breadth was 4 feet and the length 120 feet.

Iter was a road for pedestrians and horsemen, the breadth of which was 3 feet.

Semita was only half the breadth of the Iter, and when it crossed fields it was called *Trames*, *Diverticulum*, and *Divertium*.

Callais was a road through mountainous districts, for the purpose of attending the flocks.

"The unpaved roads of the Romans were called by Ulpian *vias terrenas*, to distinguish them from those dressed with stone or gravel, and they were regulated by similar laws and ordinances to the others. The road from Spain into Italy, through Nismes, was of this kind, and only passable during the summer months.

"In the winter and spring it was in a soft state, from the water which came down from the neighbouring mountains, though Strabo mentions several wooden and stone bridges and ferries. These roads, so liable to be broken up by the torrents, were exposed to the action of the sun and wind, all shade being removed, that they might speedily dry.

"The whole Roman Empire comprised eleven regions, viz., Italy, Spain, Gaul, British Isles, Illyria, Thrace, Asia Minor, Pontus, the East, Egypt, and Africa, and these were divided into 113 provinces, traversed by 372 great roads, which, according to the Itinerary of Antoninus, were together in length 52,964 Roman miles." †

In Peru the Incas appear to have built great roads. That from Quito to Cuzco was between 1500 and 2000 miles in length and 20 feet wide; it was situated at an elevation of over 12,000 feet above the sea level. This road was characterized by having a running stream and a row of trees on either side, while the road itself was paved with stones 10 feet square, and in some instances with stone covered with bitumen.

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* Cresy's *Encyclopædia of Civil Engineering*, 1847.

† *Ibid.*

Humboldt, in his *Aspects of Nature*, speaks of this mountain road as "a marvellous work, not inferior to the most imposing Roman roadways"; while Prescott, in his *History of Peru*, says of this road that "it was conducted over sierras covered with snow; galleries were cut through the living rock; rivers were crossed by means of bridges swung suspended in the air; precipices were scaled by stairways hewn out of the native bed, and ravines of hideous depth were filled up with solid masonry."

Among the many magnificent engineering works carried out by the Romans, the public roads ranked pre-eminently high, and great labour and expense were incurred in their construction. It is not to be wondered at, therefore, considering the importance of these works, that only those of the highest attainments were considered as having the necessary qualifications to supervise these great works of prominent utility.

Early French Roads.—As the Romans conquered states, roads were introduced for the benefit of commerce and society, and the art of constructing them on the Roman method was practised in France till about the beginning of the eighteenth century. A cross-section of these roads is shown in fig. 2.

The material forming the road was composed of flat stones laid by hand in two or more layers for a width of 18 feet on the bottom of the excavation; on this foundation a layer of small stones was spread and beaten down, and the surface finished with a layer of stones broken smaller than the underlying material. The usual thickness of the body of the road was 18 inches in the centre and 12 inches at the sides. The roads in France down to the year 1764 were maintained by statute labour (*la corvée*) which was only effected twice annually, in the spring and autumn of each year, necessitating the application of large quantities of stones to carry the traffic during the intervals between repairs. After the suppression of statute labour (1764) the mode of constructing new roads was considerably modified, and in the year 1775 M. Trésaguet adopted the method shown in section at fig. 3. The excavated portion was made parallel to the finished surface of the road and 10 inches below it. The bed of stones was laid edgewise and beaten to an even surface, over which a second bed of smaller stones was laid by hand, the finishing layer being of broken stones the size of walnuts, and spread with a shovel. The rise of the road was 6 inches in the centre, the

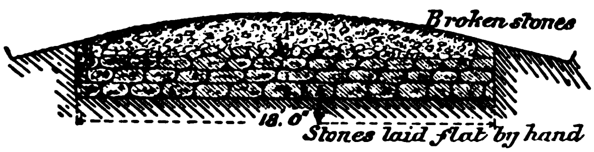

FIG. 2.—Cross-section of French road (Roman method) previous to 1775.

material for finishing the road or upper surface being selected from the hardest quality of stone.

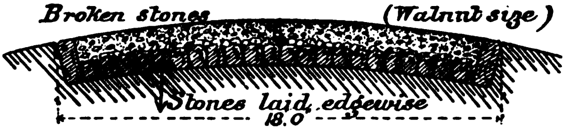

FIG. 3.—Cross-section of French road, as constructed by M. Trèsaguet in 1775.

Later French Roads.—This mode of constructing roads in France was practised till about the year 1820, when the system of Macadam attracted attention; the peculiar virtue of angular broken stones in consolidating and forming a hard surface was recognized, and the system was officially adopted in 1830 for constructing roads in that country.

M. Dumas, engineer-in-chief of the Ponts et Chaussées, writing in 1843,* stated that the system of Macadam was generally adopted in France, and that the roads were maintained in good condition by continuous and watchful attention in cleansing and repairing them, and realizing his motto, "The maximum of beauty."

Early British Roads.—The great Roman General Julius Cæsar carried out many paved roads in Italy, and, recognizing the vital importance of such lines of communication, extended them into the provinces; while subsequent to the year A.D. 43, main and branch roads were constructed in Britain by the Romans in almost every direction, from their military stations and camps to the coast.

"The Romans seem to have paid particular attention to the construction of roads in the distant provinces; and those of Britain, which may still be traced in various ramifications, present a lasting monument of the justice of their conception, the extent of their views, and the utility of their power. A grand trunk, as it may be called, passed from the south to the north, and another to the west, with branches in almost every direction that general convenience and expedition could require. What is called *Watling Street* led from Richborough, in Kent, the ancient Rutupiæ, north-east, through London to Chester. The *Ermine Street* passed from London to Lincoln, thence to Carlisle, and into Scotland. The *Foss Way* is supposed to have led from Bath and the western regions, north-east, till it joined the Ermine Street. The last celebrated road was 'Ikeneld' or 'Ikneld,' supposed to have extended from near Norwich, southward into Dorsetshire." †

Although there is no trace of Roman influence in the construction of later roads in Britain, still in many cases those made by them form the foundations of existing roads in different parts of the country. Many traces of the remains of Roman Roads, often situated at a considerable depth below the surrounding ground of the present day, have been discovered from time to time. One of the latest discoveries was disclosed when carrying out storm-water drainage works at Rochester in 1897, the details of which may be given.

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* *Annales des Ponts et Chaussées*, 1843.

† Pinkerton's *Geography*, vol. i. p. 20.

"When the Romans made the great way from the Kentish coast to the north of England, a wooden bridge, built upon piles, was thrown across the Medway. On reaching the Strood side of the river the engineers were confronted with a marsh of about 355 yards in width. This difficulty they boldly overcame by constructing upon the alluvial deposit a magnificent causeway.

"A section of the buried work showed the following:—(1) Layers of post-Roman roads for a depth of 2 feet 8 inches; (2) paved surface of causeway, 6 inches to 8 inches; (3) small pebble gravel, mixed with black earth, rammed, 9 inches; (4) flints, broken fine, 7 inches; (5) rammed chalk, 5 inches; (6) flints (white, and rather large), rough pieces of Kentish rag, fragments of Roman tile, 3 feet 6 inches; (7) marsh mud, containing numerous oak piles about 4 feet in length, with pieces of wood laid at intervals across them, or perhaps they were originally made fast by nails. The width of the causeway was about 14 feet, while the distance apart of the wheels of the waggons has been estimated, from the grooved wheel-track, at 4½ feet." *

The construction of this part of the road passing through Rochester corresponds very nearly with that described at page 3, and designated *contignata pavimenta*, being the method adopted by the Romans when forming roads across marshes in Italy.

The depth of the material forming the roadway, above the timber foundation, amounting to 5 feet 10 inches, appears to be considerably greater than that usually adopted by the Romans in similar circumstances.

For a considerable period after the occupation of Britain by the Romans the roads made by them were the only means of internal communication, but during the Dark Ages they were allowed to fall out of repair and finally into ruin, and were in many instances overrun with forest and waste until they assumed a condition probably the worst in Europe. At this period communication between towns was both difficult and dangerous; the roads which formerly had such a beneficial effect on the country were regarded with terror as aids to plunder, and in the year 1285 owners of land were enjoined to widen the roads, by cutting down trees on each side to a certain width, the inland commerce, such as it was, being maintained principally by rude paths or horse-tracks, traversed by pack-horses.

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* The foregoing description is abstracted from a pamphlet on "Roman Discoveries," by G. Payne, F.L.S., F.S.A., reprinted from *Archæologia Cantiana*, 1898.

"In very early periods of English civilization, while the population was thin and scattered, and men lived by hunting and pastoral pursuits, the track across the down, the heath, and the moor sufficiently answered their purpose. Yet, even in these districts unencumbered with wood, where the first settlements were made—as in the downs of Wiltshire, the moors of Devonshire, and the wolds of Yorkshire—stone tracks were laid down by the tribes between one village and another. In some districts they are called trackways or ridgeways, being narrow causeways usually following the natural ridge of the country, and probably serving in early times as local boundaries. On Dartmoor they are constructed of stone blocks, irregularly laid down on the surface of the ground, forming a rude causeway of about 5 feet or 6 feet wide." *

"In 1346 a law was passed to levy a toll on some of the roads leading out of London, which were reported to be impassable. In the reign of Henry VIII. (1509-1547) laws were enacted binding the several parishes to take care of the roads, and annually to select qualified persons to superintend them; but simple as are the principles of road making, those appointed are seldom sufficiently instructed on the subject, and being ratepayers, are too much interested to allow of the requisite outlay. Thus many of the parish roads are in a wretched condition, the system adopted by most parish surveyors being merely to fill up the ruts and inequalities with stones picked from the surface of the land, or gravel dug in some convenient spot; this operation repeated in the spring and autumn constitutes their whole duty; no attention being paid to the nature of the soil, or the selection of the material that will bind with it to form a hard exterior crust." †

No serious attempt was made, however, to restore the highways until the introduction of the turnpike system, after the restoration of Charles II. Acts were passed in the year 1653 for widening and repairing some of the public roads, and turnpike gates were first legally erected in England in 1663. The first relates to that from London to Scotland, which passed through Hertford, Cambridge, and Huntingdon, where toll was levied on all but foot-passengers, owing to the road becoming very bad through the heavy loads of barley passing over them in wagons and carts.

The roads in Scotland, although having lighter traffic and better materials for repairs, were said to be in an equally unsatisfactory state. The first stage-coach in Scotland was run between Edinburgh and Leith in 1610. In 1658 there was a fortnightly stage-coach between Edinburgh and London, but it was afterwards discontinued for many years. Acts

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* Smiles' *Lives of the Engineers*.

† Cresy's *Encyclopædia of Civil Engineering*, 1847.

were passed in the Scottish Parliament of 1661, 1669, 1670, 1685, and 1686, having reference to the making, up-keep, and control of roads, and many other Acts of a local as well as general application were subsequently passed into law for the improvement of public roads. These had reference chiefly to statute labour roads as a means of communication in the different parishes.

The unsettled state of the country in the Northern and Western Highlands of Scotland, culminating in the rebellion of 1715, brought about the necessity for making roads through the heart of these mountainous strongholds. The carrying out of these was entrusted to General Wade, who, between the years 1726 and 1737, constructed about 250 miles of roads, which were of the greatest value to the country. For the most part the width of these roads was 16 to 18 feet, and they had a pitched foundation covered with small stones and gravel. Many exciting scenes were enacted in close proximity to them during the smuggling days, when military escorts were common, and before highway robberies were put down. In later times, and before railways were introduced, these roads were much used for the transit of great herds of cattle to the southern markets.

Legislation, during that period, seems to have been a strong point in connection with road administration, as appears from the following:—"It is curious to refer to the progress made in turnpike legislation, which may be thus stated: from 1700 to 1710, twelve turnpike Acts were passed; from 1710 to 1720, twenty-one; from 1720 to 1730, seventy-one; from 1730 to 1740, thirty-one; from 1740 to 1750, twenty-nine; from 1750 to 1760, one hundred and eighty-five; from 1760 to 1770, one hundred and seventy-five; making, up to this period (seventy years), five hundred and thirty Acts of Parliament which had received the royal assent. These Acts were limited to a duration of twenty-one years, as it was presumed that at the end of that period the tolls imposed would not be required; the clerks of the several trusts always take care, however, that some creditors of the road should remain unpaid, by which means they contrive to keep the trust alive, and prevent their own office becoming extinct. The renewal of the Turnpike Act is also profitable to the clerk, and since 1830 the term has been prolonged to thirty-one years; at present (1847) the trusts in existence exceed 1100."*

With all this array of Acts for the making and maintaining of highways one may imagine that great improvements would have become general; this, however, does not appear to have been the case, at all events in the north of England, as the following will show:—

Mr. Arthur Young, in his *Six Months' Tour*, published in 1770, writes of some of the roads in the north of England:—"*To Wigan.* Turnpike—

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* Cresy's *Encyclopædia of Civil Engineering*, 1847.

I know, in the whole range of language, no terms sufficiently expressive to describe this infernal road. Let me most seriously caution all travellers who may accidentally propose to travel this terrible country to avoid it as they would the devil, for a thousand to one they break their necks or their limbs by overthrows or breakings down. They will here meet with ruts, which I actually measured 4 feet deep, and floating with mud only from a wet summer; what, therefore, must it be after a winter? The only mending it receives is tumbling some loose stones, which serve no other purpose than jolting a carriage in the most intolerable manner. These are not merely opinions, but facts; for I actually passed three carts broken down in those eighteen miles of execrable memory." The turnpike to Newcastle was also bad, and is described in a similar forcible manner.

From the third report of the Parliamentary Committee on Turnpikes and Highways, 1809, it appears that a convexity of considerable elevation was generally adopted in repairing roads with a view to keep them dry. The convexity, approaching the form of a semicircle, was such that vehicles kept entirely to the centre of the road, the sides being dangerous; deep ruts were formed, which retained large quantities of water and mud, and in a short space of time the road became impassable, thus defeating the object for which it was constructed. Clods, rushes, soil, and all other materials, soft and hard, where thrown down in a promiscuous manner to give the convexity desired, this being surmounted with stones from old footpaths, with a small quantity of gravel raked over them to keep them together. Fig. 4 shows a cross-section of an English road in 1809, the dark portion indicating the state of the road previous to being repaired as described above; the light shaded portion represents the appearance of the road after the repairs were carried out, and previous to the inspection by two magistrates on their way to the quarter session, who certified "that it was perfectly smooth when they saw it, and that a vast deal had been done since the last time they were there."

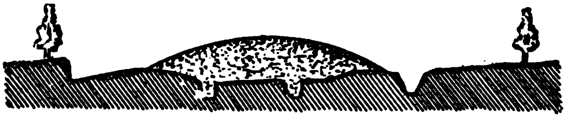

FIG. 4.—Cross-section of English road, about 1809.

Travellers when setting out on a journey used to be armed with such weapons as blunderbusses to protect themselves against the highwaymen frequenting the roads in most counties. For similar reasons, and on account of the bad state of the roads, wills were always made previous to undertaking a long journey by stage-coach or post-chaise.

Great opposition was encountered as the extension of the turnpike system became general. Armed bodies of men assembled with the object of destroying the turnpikes and burning down the toll-houses. So great was the contempt of the people for the new order of things, that in some districts they would not even use the new roads after they were constructed. The counties in which the greatest disaffection manifested itself were Yorkshire, Somersetshire, Gloucestershire, and many of the counties in Wales.

The carrying of the mails by stage-coaches and the ever-increasing exchange of different commodities about the beginning of the last century, exercised the public mind as to the importance of having main roads constructed between distant centres of population and the coast. Enormous sums of money were spent in road construction between the years 1780 and 1830, during which time most of the turnpike roads in Scotland were made. They were for the most part well laid out and constructed, material of a suitable nature being abundant in most counties. The road proper, exclusive of the ditches and fences, had a minimum width of 20 feet, while many were made from 35 feet to 40 feet wide.

The intermittent and unsatisfactory manner in which road repairs were carried out in this country up to about the beginning of the last century appears to have been intolerable, and no real improvement was effected (although Metcalf made many new roads successfully) till the advent of Macadam and Telford. These two latter road-makers were contemporaneous and in some respects advocates of rival systems, and may be looked upon as the pioneers of good road construction. The methods adopted in effecting improvements and repairs were based on scientific principles, and the building of many bridges, where fords and ferries formerly existed, established a better means of communication between different parts of the country.

Metcalf.—John Metcalf was born at Knaresborough in 1717, and had the misfortune to lose his sight through illness, when only six years of age. After being successively a fiddler, soldier, horse-dealer, and carrier, he seems to have undertaken in 1765 a sub-contract for constructing a portion of the new road between Boroughbridge and Harrogate, extending to three miles, a trusty foreman carrying out his plans. As a road-maker his operations extended to Lancashire, Cheshire, Yorkshire, and Derbyshire, in which counties he constructed about 180 miles, involving in some instances the erection of many bridges, the building of retaining walls and culverts, and crossing difficult bogs in a successful manner. Metcalf died in 1810 at the age of ninety-two.

Macadam.—John Loudon Macadam was born at Ayr, in Scotland, in 1756, and educated at the parish school of Maybole. He passed his youth in the United States of America, but returned to Scotland at the close of the War of Independence (1783). Immediately thereafter he acted as a road trustee, was appointed manager of a district in Ayrshire,* and originated and successfully practised for many years the system of road making and repairing now known by his name. He held a government appointment from 1796, and resided in Falmouth and afterwards in Bristol, when, in 1815, he was appointed surveyor of roads in the latter town. It was in Bristol, where the roads extended to 178 miles, that he had full scope for putting into practice the great improvements in road making which had occupied his thoughts, and which he had successfully carried out when in charge of the Ayrshire roads many years previously. This was "to put broken stone upon a road, which shall unite by its own angles so as to form a solid hard surface." "It follows," he adds, "that when that material is laid upon the road it must remain in the situation in which it is placed without ever being moved again, and what I find fault with in putting quantities of gravel on the road is that, before it becomes useful it must move its situation and be in constant motion." * The distinctive novelty of Macadam's system, the value of which has been established by universal experience, was to substitute small angular stones, prepared from larger pieces, for the large rounded stones then generally made use of in road repairs.

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* Chambers's *Encyclopædia*.

Macadam's system of construction was simply to spread broken stones, 2 inches in diameter, equally, so as to form a layer about 10 inches thick over the road surface, after it has been levelled and properly drained where necessary. The convexity given was just sufficient to cause the rain-water to run readily off the surface into the side channels.

Macadam found the roads in the Bristol district loaded with material of large and irregular size, to the extent of from 2 to 3 feet in thickness. This great amount of rough material (limestone) he utilized by lifting or excavating the whole mass, separating it from the mud, and breaking the stones to a uniform size of 6 oz. in weight. The formation of the road was then properly levelled, and drainage introduced where necessary, the metal prepared from the rough material being carefully relaid, and regularly raked during the process of consolidation by the carriages passing over it. The surface of the roads was kept even and clean by the addition of proper fresh materials, when necessary, distributed equally in thin layers immediately after rain, in order that the new materials might bind and incorporate properly with the old. Macadam strongly condemned the use of binding material for filling up the interstices in the metal, which he left to work in and unite by its own angles by means of the traffic. He says "that every road is to be made of broken stones, without mixture of earth, clay, chalk, or any other matter that will imbibe water and be affected by frost."

When reconstructing or repairing a road, Macadam endeavoured to have the whole of the material composing it higher than the surface of the adjacent ground, so as to give every facility for the water to escape from the bottom as well as from the surface of the road. The size of metal adopted

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* *Report of the Select Committee on the Highways of the Kingdom*, 1819, p. 22.

by Macadam was that of a cube of 1½ inch; he preferred, however, to specify the weight of the stone, and insisted that it should not weigh more than 6 oz.

His system of maintaining the surface of a road was found so beneficial that he was engaged as general surveyor by many of the road trusts in England and Scotland. By his business-like and extended views on road administration, he not only reduced the debts previously incurred and placed the finances of the many trusts on a sound basis, but established for himself a world-wide reputation.

In 1824 the Road Trustees of the Carse of Gowrie Turnpike Road (Perthshire), between Perth and Dundee, consulted Macadam as to the repairs on this highway, which was gradually falling into a state of such great deterioration that travelling over it was disagreeable, while the Trustees had been threatened with a prosecution at the instance of the Post-master-General on account of the delay occasioned to the mail coaches. The Trustees considered the annual expenditure for the maintenance of this road beyond what they deemed necessary under the circumstances. From the correspondence which took place between the Road Trustees and Macadam, it would appear that the prevailing practice in Scotland and many districts in England, when forming new roads, was to excavate a trench or metal box in which the stones were placed; in other words, the material was deposited below the natural surface of the ground, so that a mound of earth was raised on either side of the metal bed. The subsoil in this part of the country through which the turnpike road passed being of retentive clay, Macadam decided to lift the existing road, and thoroughly drain the road bed. He also found it necessary to break the large stones, some of which were 9 inches in diameter, to a regular size, and relay the metalling carefully, any deficiency in quantity being made good with a supply of fresh materials. The result of these improvements was a thoroughly serviceable road, and the expressions of gratitude conveyed to Macadam by the Carse of Gowrie Road Trustees is a clear proof of the great benefit arising from the system adopted in repairing their roads; the saving effected in the maintenance placed the funds of the Trust in a sound financial position. It may be interesting to note that, at the time when Macadam was engaged by so many road trusts, he had a staff of 300 sub-surveyors under his charge. In 1827 he acted as General Manager of the Metropolitan Roads. The system advocated by Macadam was so popular at one time that expensively paved streets, such as that between Edinburgh and Leith, were torn up to be remade by the new process. On streets having an excessively heavy traffic, Macadam's system of construction has no place, and Dublin is instanced as a failure of his method of road repairs.

It is said that Macadam was anticipated in his system of a regularly broken stone covering by Mr. Edgeworth, an Irish proprietor, whose system was advocated in *An Essay on the Construction of Roads and Carriages*, a second edition of which was published in 1817. An article which appeared in the *Westminster Review* in 1825 states that "The name of Mr. Macadam deserves a few remarks for other reasons than its present popularity. The public naturally took to him as a sort of magician, and his invention, as it is thought, as something preternatural."

"If his own name had not been macadamizable into a verb, it is probable that his roads would have been little known. He did not invent the method in question of breaking stones, because it had long been the practice of Sweden, Switzerland, and other countries, and was long known to every observing traveller." *

In view of what has been stated, it seems curious that the road engineers in France, where the highways were considered, at the beginning of the last century, to be superior to any in Europe, should not have adopted the system which it is said prevailed in the countries mentioned, in preference to Macadam's method, which was practised between 1820 and 1830 and officially adopted in that country at the latter date.

It may be further mentioned that the system promulgated by Macadam was practised by him in Ayrshire at least thirty years previous to the appearance of Edgeworth's essay or the article referred to in the *Westminister Review.*

It is considered by all impartial observers that Macadam was the pioneer of good road construction and administration, and by his practical abilities was entitled to the reputation of a public benefactor. He died at Moffat in 1836 at the age of 80 years.

Telford.—Thomas Telford was born in the district of Eskdale, in the county of Dumfries, on the 9th of August 1757, and obtained the rudiments of his education in the parish school of Westerkirk. Learning the trade of a mason, he subsequently studied architecture in Edinburgh, and latterly in London, and being a man of ability he soon established himself as a leading engineer.

Bridge building was his great forte, but he carried out many other engineering works, particularly that of laying out and constructing new roads in all parts of the kingdom. He held the appointment of Surveyor of Public Works in Shropshire subsequent to the year 1787, and in that capacity he erected many fine bridges over the Severn.

His first undertaking as a road-maker on an extensive scale was in the Highlands of Scotland, whither he was sent by the Government in 1802 to report as to the best means of developing the resources of the country.

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* *The Westminster Review*, vol. iv. (July, October) p. 354. "The Commercial Power of Britain." By the Baron Dupuit, etc. Translated from the French. C. Knight, London, 1825.

He advised the opening out of the country by a complete system of roads, so as to bring the interior parts into communication with the towns and the coast.

Under his direction, and by the aid of Parliamentary grants, amounting to £450,000, roads extending to 920 miles were laid out and constructed, and owing to the hilly and rugged nature of the country, works of considerable magnitude had to be undertaken, including 1117 bridges. This work was carried out in the course of eighteen years, under 120 contracts, and without recourse being had to a court of law in any one instance.

The following specification, drawn up by Telford and referring to the construction of the Highland Roads, is given in detail, having a peculiar interest, especially at the present time, in so far as it refers to one of the largest pieces of road making undertaken at any time in this country.

General Specification for the Highland Roads.

"The road to be formed to the full breadth of 20 feet in the clear, including the side drain and green margin, except on places where there is an absolute necessity for cutting the whole breadth of the road in solid rock; and in those places the breadth of the road shall be 18 in the clear, between the parapets which may be necessary for a safeguard, and those parapets are to be 2 feet in thickness at the bottom, so that in rock the cutting will be 20 feet in breadth, and in all cases the road is to be so laid out, that there shall be no quick bendings, nor its upper side interrupted by points of rock.

"On dry bottomed ground, gravel of a proper quality, out of which all stones, above the size of a hen's egg, shall have been previously taken, shall be laid to a depth of 14 inches in the middle, and 9 inches at the sides; but the stones which are taken out of the gravel, and do not exceed 4 inches in size, may be laid for that thickness below the gravel, and in that case 10 inches only of cleansed gravel will be required.

"On mossy ground or swampy soils, if the moss or soft matter is not more than 2 feet in thickness, and a hard bottom below this moss or soft matter, it is to be wholly removed, and the road formed on the harder substance as above described; but when the moss or soft matter is more than 2 feet in depth, the contractors are to have their option of either removing it, or forming the road upon the top of it in the following manner.

"Where the surface is level, and covered with sound sward or heath, there must be laid two rows of swarded turf, with the swarded side of the one downwards and of the other, which is to receive the gravel, upwards; or otherwise, where turf cannot be readily procured, the surface of the moss or soft matter may be covered with a layer of brushwood or heath, which, when compressed, shall not be less than 6 inches in thickness; upon the surface so compressed and prepared, there shall be laid gravel, cleaned as before described, to the thickness of 18 inches in the middle and 13 inches at the sides.

"In all cases, whatever be the nature of the soil, the road is on all the flat ground to be brought to a perfect level from side to side, before the gravel is laid on; but in all cases where the road is to be raised on the one side by moved ground, while the upper side is on the natural ground, the lower side of the road, when finished, is to be from 4 to 6 inches higher than the upper side, in proportion to the quantity of moved ground on the lower side.

"In side cuttings in steep banks, even if there is no moved ground on the lower side, still the lower surface of the finished road is to be on at least 4 inches higher level than the upper side. Where the ground is level or flat, the road is to be gravelled to 18 feet in width, and to have a border of green turf on each side, 1 foot in width.

"When the road is formed on a sloping bank, where no parapets are necessary, there is to be a border of green turf on the lower side of the road, 1 foot in breadth in the clear.

"The drains are to be formed perfectly regular, and so as the course of the water shall not be interrupted by points of rocks or sudden turnings; and where the soil is soft and loose, these drains on the upper side of the road are to be paved with small stones, not less than 4 inches in depth. These pavements are to be made at the places pointed out by the inspector; they are to be carried to the extent, and made in the shape, he shall direct.

"Where the parapets are necessary, the road is to be gravelled to the breadth of 18 feet as before described. And also the said contractors bind themselves and their foresaids to make in a sufficient manner all back drains, of such dimensions, and in such directions, as shall be necessary for effectually collecting and conducting the water in a proper manner from the higher grounds to the nearest bridges or covered drains, especially where the road is formed along steep and sloping banks, and the ground is wet and swampy, and that at the places which shall be pointed out by the said surveyor, so that the road shall always be kept free from water.

"Where the road is to be formed upon level ground, and particularly where it is mossy and swampy, side drains are to be made of sufficient depth to drain the ground, and in all cases quite sufficient to carry off the water. These side drains to be made with a slope from the road to within 1 foot of the further side of the drain, so that if the depth at the further side be 30 inches, the width at top shall be 6 feet, and so more or less in proportion to the depth, and which side drains shall be made at the places approved of by the surveyors: and also to make covered drains of dry stones at all places where necessary; the inside walls of these drains are not to be less than 2 feet in thickness, and the stones for that length to be laid regular: these covered drains shall in no instance (without particular directions in writing from the principal engineer employed by the Commissioners) be less than 2 feet square; they are to be properly secured in the bottom by paving with stones set on edge; the pavement as well as the sides are to be secured at both ends of the drains by stone work, so that it shall appear evident there is no risk that they shall be injured by the water, where it enters into or issues from the drain. The stones with which the 2 feet drains are covered are to be not less than 3 feet in length and 4 inches in thickness, and laid so close together on stones of equal length overlapping each joint, as shall effectually prevent the gravel from passing down into the drain, and leaving a hole in the road. But in case it shall be discovered during the execution of the road that, instead of some of the 2 feet, the road may be better protected by making a greater number of drains of smaller dimensions, the contractors, upon receiving instructions in writing from the principal engineer, shall execute them in such a manner, and counting two drains of 18 inches, or three drains of 12 inches, in lieu of one drain 2 feet square, and in case of drains of 18 inches being made, the stones of the covers shall not be less than 30 inches in length; if 12 inches, the covers to be 2 feet in length; and in order to secure the due execution of the said covered drains, it is expressly declared that the same shall be subjected to the inspection and approval of the resident surveyor before the covers are laid on, that he may be satisfied that the bottoms are properly paved, and the sides are built in a sufficient manner; and after the said drains are covered, the backs of the buildings are to be made up with stones to the level of the upper beds of the covers, and the said drains shall be constructed so that they shall have a sufficient covering of gravel, not exceeding 12 inches, to the satisfaction of the surveyor, without causing any swell on the road. And also the said contractors bind and oblige themselves, and their foresaids, to build and erect breastworks of stone at all places where necessary on the lower side of the road, along the side of water-courses, or on sloping banks, or on rocks; the foundation of the said breastwork must be cut into the rock or solid ground for the whole breadth of the base of the wall or breastwork which is to be placed on it, as hereafter described, and its direction is to be dipping into the hill at a right angle with the slope of the face of the breastwork. If it shall be necessary to make the breastwork 3 feet in height, from the foundation to the level of the lower side of the road, the breadth of the foundation shall be 24 inches, and 18 inches at the top, or level of the lower side of the road. If the height is 4 feet, the breadth of the foundation is to be 30 inches, and at the top 24 inches. If the height is 6 feet, the breadth at the foundation is to be 3 feet, and 2 feet at the top. If the height is 8 feet, the breadth of the foundation is to be 4 feet, and at the top 2 feet, and so on in proportion to any greater or lesser height. In forming these breastworks, the stones are to be laid in regular manner, quite through the thickness here described; the slope which is necessary to bring the wall to its thickness at the top is all to be taken off the outside, and the stones are to be laid mostly lengthwise into the wall; the space behind the breastwork and natural ground, up to the level of the top of the formed roadway, is to be filled up with coarse gravel or stones (neither sand, sods, nor moss to be used), and if with stones they are to be covered and brought to the levels formerly described, with a layer of strong swarded turf, before the cleansed gravel is laid on.

"At all times, when the nature of the cutting makes it possible, the resident overseer shall have an opportunity of examining the breastwork when completed, before the inner side shall be filled up with stones or gravel as aforesaid; and also, where it shall be necessary for the due execution of the said road, to erect parapet walls above breastworks, or upon rock, they are to be built with stones laid in good lime mortar, agreeably to the ground report.

"These parapets are to be 2 feet wide at the foundation, and 18 inches at the top. The height above the finished roadway is to be 2 feet 9 inches, including a coping of stones 9 inches deep. These coping stones are to be chosen so as to meet one another in close regular beds or upright joints, to be firmly wedged together, and pointed with lime mortar.

"At each extremity of the parapets the copings are to be well secured with the ends turned down under the roadway, and also where it shall be necessary in forming the road, to cut and remove earth from the higher side, to the depth of 2 feet or more, the road must be formed 21 feet 6 inches wide, and, to prevent the earth from falling into the drain on the upper side of the road, a wall of dry stones must be erected of a height according to the depth of the cut. The foundation of these retaining walls is to be laid in all cases 6 inches below the bottom of the drain, on the upper side of the road: there the thickness is to be from 15 to 18 inches to the height of 4 feet; above that height, they are to be one-third of the thickness. The stones with which they are to be constructed are to be laid in a regular and workmanlike manner for the whole thickness of the wall: they are to be carried to such a height, that the slope from them to the solid ground of the bank above is not to be less than two horizontal to one perpendicular, and that slope to be covered with turf laid flat.

"And further, the contractors are to be bound to cut down all heights, fill up all hollows, and blast all rocks upon the said line of roads, as pointed out by the said reports, and which shall be requisite and necessary for the same: and further, the said line of road shall be formed and prepared for the gravel for one mile at least per advance to the satisfaction of the surveyor employed by the said commissioners before any of the cleansed gravel is laid on."*

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* Cresy's *Encyclopædia of Civil Engineering*, 1847.

Where the ground on which the road materials were to be spread was of a soft nature, a concrete foundation composed of lime and gravel or hard stone, and varying in thickness from 6 inches to 12 inches, was spread over the entire surface, and broken stones laid on before the concrete became set, so that it might bed itself and become firmly united with it.

Telford, in 1816, directed the works in connection with the improving of the road between Glasgow and Carlisle, the old road having become impassable. The improvement and reconstruction of this road were undertaken as a work of national importance, and £50,000 were granted by Parliament with this object. The method of constructing this road differed materially from those carried out in the Highlands, as it was necessary to provide for the transit of the mail and heavy coaches, the gradients being made easy, not exceeding 1 in 30. The old road was in length 102 miles; the existing one is not more than 93, and in order to gain this nine miles it was necessary to reconstruct 69 miles entirely, and to build fifteen new bridges, excluding which the cost of the road making was about £1000 per mile. It was specified "that the breadth was to be 34 feet between the fences, 18 of which were to be metalled, and the remaining 8 feet on each side to be covered with gravel. In all embankments the width on the top to be 30 feet, and the side slopes 1½ horizontal to 1 perpendicular; in all cuttings above 5 feet the width between the lower skirts of the slopes 30 feet, all below that depth to be 34 feet. The slopes of all the cuttings to be at the same rates as the embankments.

"The surface of the road longitudinally, or lengthwise, in all cases where there were cuttings and embankments, to be formed as shown, and in no instances the ascents or descents to exceed 1 in 30, and the changes from one to the other to be made in regular curves, to the satisfaction of the inspector.

"Where there were side cuttings, and a part of the road made on moved ground, the surface of the lower part or moved ground to be higher than that of the upper side to allow for consolidation, so that when finished it might have the proper level. In the middle of the road a metal bed to be formed, and in all cases where the ground was nearly level, the metal to be laid upon the natural surface of the ground, so as to have a curvature of 4 inches, in the middle 18 feet, and the sides or shouldering to be made with moved ground, but on no account is the metal bed to be cut out of the natural ground, unless that be loose gravel or rock.

"The metalling to consist of two beds or layers, viz., a bottom course of stones, each 7 inches in depth, to be carefully set by hand, with broadest end downwards, all cross bonded or jointed, and no stone to be more than 3 inches wide on the top. These stones to be either good whinstone, limestone, or hard freestone; the vacuities between to be carefully filled with smaller stones packed by hand, so as to bring the whole to an even and firm surface.

"The top course or bed to be 7 inches in depth, to consist of properly broken stones, none to exceed 6 ounces in weight, and each to pass through a circular ring 2½ inches in diameter in their largest dimension. These to be of hard whinstone, the quality of both bottom and top metal to be determined by the inspector. In every 100 yards in length on each side of the road, upon an average, there was to be a small drain from the bed of the bottom layer to the outside ditch, as directed by the inspector. When the height of the embankments exceeded 3 feet, they were to stand from one to three months, in proportion as they increased in depth, as determined by the inspector. Over the upper bed or course of metal to be a binding of gravel of 1 inch in thickness upon an average; the cross-section of the finished roadway to have a curvature of 6 inches; in the middle 18 feet, and from that on each side a declivity at the rate of half an inch in a foot, to within 18 inches of the fences; the remaining space of 18 inches to have a curvature of 3 inches, making in all about 9 inches on each side below the finished roadway.

"In passing morassy ground all the surface upon which the road is to be placed, viz., between the fences, to be brought to a curvature of 12 inches in the middle, and to be secured with two rows of good swarded turf, the lower end to be laid with the swarded side downwards, and the upper one with it upwards. The metalling upon the said mossy ground to be made 20 feet in width; a drain to be cut alongside of the road, 4 feet wide at the top, 18 inches at the bottom, and 3 feet deep.

"*Cross Drains.*—Nine to be made in every mile in length, placed in situations marked out by the inspectors; 18 inches wide, 16 inches high at the upper end, and 22 inches high at the lower end; their bottoms to be paved with flat or small pebble stones, 4 inches in depth. The foundations of the side walls to be laid at least 6 inches below the level of the bottom of the drain, and these not to be less than 18 inches in thickness, laid in regular courses, faced on both sides in the manner of a good stone dyke. The top of each to be properly levelled, and covered with a firm turf 2 inches in thickness to form a bed for the covers. The covers to be 2 feet 6 inches in length and 4 inches in thickness; their side joints to be made straight, so as to unite closely, the parts which lie on the turf to be flat.

"These drains must be of a length not only to cross the road, but the fences on each side, also the slopes of the embankments, and pass fairly into the fields or natural water-courses; from the ends of the drain, wing walls to be extended 5 feet in a curved direction into the solid ground, these to be of the same thickness as the side walls, founded at the same depth, and carried to the same height, and coped with two rows of swarded turf. The bottom between the wing walls to be paved with stones not less than 6 inches in depth, and well secured at the extremities by stones 12 inches in depth, and these to be well secured at the upper ends, and connected with the firm ground and side drains. The whole body of the drain to be of such a depth as to admit of a turf being laid over the covers, and the full quantity of road metal and binding, without raising the longitudinal line of road. At each end of the cross drains, the water which passes along the side of the road to be introduced by a proper opening, protected by a stone cover; this entrance to be paved at least 5 feet in length. In passing through morassy ground, the bottom of the drains to be laid with flat stones quite across, and at least 12 inches under each side wall, to be continued quite to the extremity of the wing walls.

"To keep this road in repair after it was made required at the least 80 cube yards of broken stone per mile, and at the most 120 per annum; the cost of which varied from £20 to £46 per mile." *

Fig. 5 is a cross-section of the Glasgow and Carlisle Road, showing *cross* and *surface* water drains.

From Scotland Telford extended his operations to England and Wales, where the roads, which had been laid out some years previously, were in such a condition as to require to be reconstructed. The Government in 1815 engaged Telford to make the Shrewsbury and Holyhead Road—one of the finest pieces of road-engineering carried out up to that time in the world, and the Menai and Conway bridges in connection with it. This road was considered, owing to its lying in the direct line of communication between England and Ireland, of sufficient importancc to be deemed a National undertaking. Its condition, along with the portion to London, was reported on annually by Telford till his death.

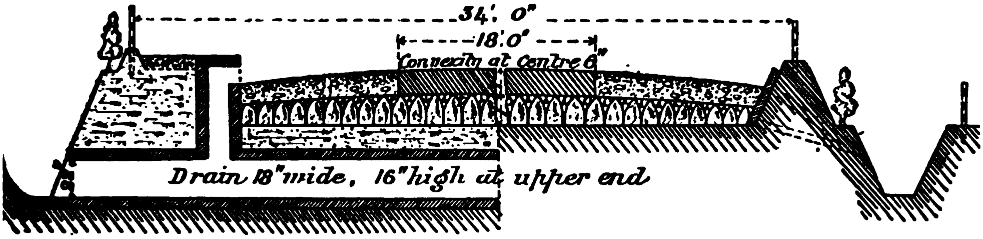

FIG. 5.—Cross-section of road showing cross and surface water-drains.

The construction of this road is practically similar to that of the Glasgow and Carlisle road, a cross-section of a 30 feet roadway being shown at fig. 6.

Such were the great improvements effected by Telford in carrying out these works, that the Select Committee of the House of Commons in reporting on the matter, stated as follows:—

"The professional execution of the new works upon this road greatly surpasses anything of the same kind in these countries.

"The science which has been displayed in giving the general line of the road a proper inclination through a country whose whole surface consists of a succession of rocks, bogs, ravines, rivers, and precipices reflects the greatest credit upon the engineer who has planned them; but perhaps a still greater degree of professional skill has been shown in the construction, or rather the building of the road itself. The great attention Mr. Telford has bestowed to give to the surface of the road one uniform and moderately convex shape, free from the smallest inequality throughout its whole breadth, the numerous land drains, and, where necessary, sewers and tunnels of substantial masonry with which all the water arising from springs or falling in rain is instantly carried off; the great care with which a sufficient foundation is established for the road, and the quality, solidity, and disposition of the materials that are put upon it, are matters quite new in the system of road making in these countries." *

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* Cresy's *Encyclopædia of Civil Engineering*, 1847.

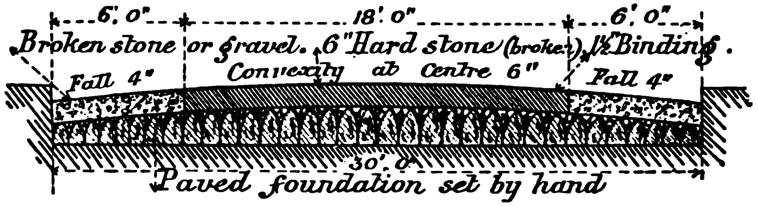

FIG. 6.—Cross-section of Shrewsbury and Holyhead Road—Telford.

The following rules were prepared by Telford in 1820, as instructions to those in charge for the proper maintenance of the road between London and Shrewsbury, at the instance of the Parliamentary Commissioners:—

GENERAL RULES FOR REPAIRING ROADS.

I. SHAPE OR CROSS-SECTION.

Rule 1.—Upon a road of 30 feet in width, the sides should be 9 † inches below the surface of the middle. The best line of the cross-section is a segment of a flat ellipse. This shape not only assists the water to pass from the centre towards the sides, but contributes to the drying of the road by allowing the action of the sun and air to produce a great degree of evaporation. Surveyors ought to use a level in giving roads a proper shape, in order that the surface may be of one uniform curvature, without the smallest deviation in any one spot from the prescribed line of the cross-section.

II. DRAINAGE.

Rule 2.—All ditches ought to be on the field side of the road fences, and to be connected with the natural water-courses of the country.

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* *Report from the Select Committee on the Road from London to Holyhead in the year 1819.*

† Telford afterwards considered 6 inches sufficient for this width.

The stone cross drains and culverts which pass under the road should be numerous, and continued through under the fences into the ditches.

In order to keep a road perfectly dry, openings of mason-work should be made from the side drains of the road into all these cross drains, to carry off the water collected from the surface of it. The bottom of these cross drains must be well paved, particularly at these openings.

It ought never to be forgotten that in order to have the surface of a road perfect, it must be kept completely dry.

All land springs ought to be carried from the side of the road by under-draining.

III. TREES AND FENCES.

Rule 3.—It is absolutely necessary to remove trees from the sides of roads, and to keep the fences under 5 feet in height. Not less than 20 per cent. of the expense of repairing roads is incurred by the trees and the improper state of the fences keeping the roads wet, and by that means occasioning the rapid destruction of the materials.

IV. MATERIALS.

Rule 4.—Where the materials are quarry or field stones, the hardest part of them should only be used. Each stone should be so broken that it may, in its largest dimension, pass through a ring 2½ inches in diameter. Hammers with slender handles, light and well-steeled, must be made on purpose for breaking them. This work ought always to be done by measure, either at the quarries or in proper recesses made for the purpose on the sides of the road. Men who are past hard labour, and women and boys may be employed on it.

Rule 5.—Where the materials consist of gravel, the stones only which exceed 1½ inch in size should be taken from the pits for the repairing of the middle part of the road, of 18 feet in breadth. These ought to be raked together as the gravel is thrown up by the workmen. This process will, in most cases, save the expense of riddling and washing the gravel. The small gravel and gravelly portions of the pit may be used for the sides of the roads and the footpaths. Every gravel stone which exceeds 1½ inch in size ought to be properly broken, either in the pits or in the aforesaid recesses. A pronged shovel should be used in putting the stones into the barrows. Surveyors should pay very particular attention to this rule, because the common use of a mixture of round gravel and clay is a public nuisance, and must be got rid of. When a surveyor obstinately persists in this practice, the trustees should dismiss him.

V. DISPOSITION OF MATERIALS.

Rule 6.—Where a road has no solid and dry foundation, it must be constructed anew. It must be well drained, and put into a proper form. Upon the 18 centre feet of it stones must be put, forming a layer 7 inches deep. Soft stones will answer, or cinders, particularly where sand is prevalent. These bottoming stones must be carefully set by hand, with the broadest end down, in the form of a close, neat pavement; the cavities should be filled with stone chips to make all level and firm, and no stone should be more than 5 inches broad on its face. This proportion of a solid and level foundation is the most essential point to be secured in order to have a perfect road, and that the draught of carriages may be eased as much as possible. Over this bottoming of stones or cinders, 6 inches of stones, of a proper quality, broken to a size that will, in their largest dimensions, pass through a ring of 2½ inches diameter, must be laid. The 6 feet of the road on each side of the 18 centre feet (making 30 feet), when formed of a proper shape, may be covered with 6 inches of good clean gravel or small stone chips.

Where a road has some foundation, but an imperfect one, or is hollow in the middle, all the large stones appearing on the surface of it must be raised and broken; the 18 centre feet of it must then be covered with a coating of broken stones, sufficient to give it a proper shape, and to form a bed of solid materials of at least 13 inches in depth, to make it solid and hard.

Where a road already has a good foundation and also a good shape, no materials should be laid upon it but in thin layers, for the purpose of filling ruts and hollow places as soon as they appear. Stones broken small, as above described, being angular, will fasten together. In this way a road, when once well made, may be preserved in constant repair at a small expense.

Where the breadth of that part of a road which alone has been formed of hard materials, and over which the carriages commonly pass, is less than 18 feet, it must be widened with layers of broken stones to that breadth, first digging away the earth and forming a bed for them with pavement and broken stones, at least 10 inches deep. Near large towns the whole breadth of the roadway should be covered with broken stones.

VI. MANAGEMENT OF LABOUR.

Rule 7.—All labour by day's wages ought, as far as possible, to be discontinued. The surveyors should make out specifications of the work of every kind that is to be performed in a given time. This should be let to contractors, and the surveyors should take care to see it completed according to the specifications before it is paid for. Attention to this rule is most essential, as in many cases not less than two-thirds of the money usually expended by day labour is wasted.

In all probability the contract system was introduced with a view to get rid of the paupers then employed on the Holyhead road, as Telford afterwards, in 1819, on some portions of this road, at least, placed foremen in charge of 4 to 6 miles of road, having under them a sufficient number of labourers to keep the road in proper shape. Further, in 1823, he says that "a certain number of labourers ought always to have the care of the surface of the road, and never quit it for a single day to do anything else; they will always have sufficient to do in spreading materials in ruts and hollows, in scraping the road, in cleaning out the side channels and keeping open the water-courses, and generally in maintaining the road in a clean and sound state. A few men constantly so employed will do a great deal towards the preservation of a road, while the greater number of workmen should be as constantly employed in providing materials by contract work."

It is noticeable, however, that in the Highlands of Scotland and in Wales, where the population was sparse and labour difficult to obtain, that he invariably adopted the contract system of maintaining the roads.

Telford, in 1830, supplemented these foregoing general rules by the following specification:—

SPECIFICATION for the regulation of the surface between the fences, so as to establish uniformity in the cross-section.

1. The road is to be 30 feet wide, with a fall of 6 inches from the centre to the side channels, but exclusive of the footpaths.
2. Two sods to be laid on each side of the road, one upon the other; the lower one 12 inches wide, the upper 8 inches, and each 4½ inches in thickness; and in such manner as to form curved edges when they grow together; the top surface of the sods on each side to be exactly on the same level.
3. On one side of the road a footpath to be made behind the sod; it is to have an inclined surface of 1 inch in a yard towards the road; and another sod to be laid along the outer edge of the footpath, 8 inches wide, on a level with the footpath.
4. On the other side of the road a flat mound of earth to be formed behind the sods, on a level with the top of them, 5 feet 8 inches wide; the surface of this mound to be made with sods or sown with grass seeds.
5. The waste land, where there is any, on each side between the footpaths or the mound and the road fences, to be dug over in the breadth of 4 feet, at right angles to the fences, and made quite smooth; when these wastes are covered with grass, the sod to be pared off each breadth and laid on the breadth last dug; when they are not in grass, the new surface is to be sown with hay seed.
6. If there is a ditch on the roadside of the fence, or if the road fence consists of a high bank, a new post and rail fence is to be made close along the footpath and mound, with a ditch on the field side at least 3 feet deep.

An instance of what can be done by proper engineering in the laying out of a new road, or improving the gradients of an existing line of communication, may be gathered from the following facts of a case in which Telford's skill as an engineer may be cited. An old road in the island of Anglesea, 24 miles in length, so undulated that a horse ascended and descended 1283 feet of vertical height more than was found necessary by the new line of road, and the distance was shortened by 2¼ miles. Another instance of what could be done in relieving the public of unnecessary and avoidable ascents, and which add greatly to the tractive power entailed, may be mentioned. On the road from London to Barnet the rise or number of perpendicular feet which a horse must now ascend is upwards of 1300, although Barnet is only 500 feet higher than London; and *vice versa*, a horse must ascend 800 feet, although London is 500 feet lower than Barnet.

The introduction of railways in this country had a disastrous effect on the turnpike system of collecting revenue, the traffic, mainly passenger, being diverted to the more expeditious and economical means of locomotion. This particularly applied to roads which connected large towns, and after the completion of the railway system, running in many cases parallel to these roads, the decreased revenue caused by the diverted traffic and revenue was of an almost revolutionary nature, thousands of stage-coaches being thrown out of employment. Many main roads became of little importance; but those, including statute labour roads, running at an angle with the railways, connecting the districts on either side, became the great feeders in the exchange of products, and for the most part require in modern times the most attention. It is not to be wondered at, therefore, that, as the railways grew in favour, the revenue of the 'turnpikes' became gradually less each year. This change in the course of events was anticipated by many before railway communication was an accomplished fact, and methods were proposed to meet the change of circumstances which would necessarily be entailed.

It was not, however, till many years after the new mode of travelling came into existence that county authorities saw the necessity for a change in the turnpike system, so as to obtain a revenue for the proper maintenance of the roads.

In 1865 and following years 'local Acts' were obtained, abolishing tolls in certain counties in Scotland, and in 1878 there was passed for this purpose a general permissive Act, which was to be compulsory after 1883, under which all roads are classified as highways.

The method of raising revenue under the old system of statute labour, generally commuted and paid for as plough gates, etc., and tolls administered by a great many trusts, with no view in common, seems to have been a very cumbrous piece of machinery. The management, apart from that of maintaining the roads, cost considerable sums in the form of profit to the tacksman, amounting in some cases, it is said, to over £9 per mile. It is very evident that this profit, in addition to the expense of repairing the toll-houses, gates, etc., formed a sum which, had it been applied direct to the maintenance of the roads, would have been sufficient to keep them in excellent condition.

The disputes arising between the collectors, the public who used the roads, and the trustees, were numerous, litigation in a perpetual form being the order of the day.

This, no doubt, was a weak spot in the turnpike system, which, combined with the introduction of railways and consequently reduced revenues, was mainly instrumental in bringing about a new order of things.

The present system of raising the necessary revenue for road purposes, viz., by assessment on rental, one half being payable by the proprietor, the other half by the occupier, appears to answer well, although those not using the highways directly consider themselves aggrieved. As, however, all articles of consumption pass over the roads, the ratepayer is saved indirectly in the purchase of all such commodities.

The extended powers for the further improvements of highways conferred on County Councils by the "Local Government Acts" (England 1888, Scotland 1889) admit of the different counties and districts thereof concentrating the management in a uniform and intelligent manner.

By these means plant for the repairing of the roads can be purchased, such as rock drills, stone-breaking machines, steam rollers, and many other appliances. Greater efficiency is, therefore, now possible by their proper application, while economy in carrying on the work of maintenance is promoted by judicious management.

PART I.

CHAPTER I.

RESISTANCE TO TRACTION—WHEELS AND WEIGHTS ON THEM.

Previous to entering upon the subject proper of road construction, it will be necessary to notice briefly the effects of the resistance to traction on a road surface, and the points to be considered in determining the ruling gradient which should be adopted on a proposed road, according to the situation, and the class of traffic likely to pass over it.

The main external forces which offer resistance to the motion of vehicles upon roads are:—Friction, collision, gravity, and air resistance.

1. External Forces affecting the Motion of Vehicles.—(1) *Friction.*—This arises from the rolling resistance of the wheel tires when in contact with the surface of the road. It involves the consumption of part of the force exerted by the prime mover. Under friction may be considered the resistance of penetration, which is brought about by a yielding road surface, that is, a weak and inferior road, or one on which gravel or loose stones have been spread, also on soft earth. In these circumstances the resistance to traction is less the larger the diameter of the wheels, as larger wheels sink less and spread along a greater surface than wheels of less diameter; the areas of immersion, however, are equal in either case.

Resistance arising from the friction of the axles is nearly constant at all velocities, and may be neglected. It may, however, be mentioned that with wheels of ordinary construction the resistance amounts to from $\frac{1}{130}$ to $\frac{1}{100}$ of the weight on the axle, or 17 to 22 lbs. to a ton of load. Friction of the wheel on its axle is independent of the condition of the surface of a road.

(2) *Collision.*—This may be caused by the want of uniformity or irregular condition of the surface of a road, or may be occasioned by hard substances, such as loose stones, which give a sudden check to the forward movement of vehicles. Considerable injury is done to a road surface by a vehicle surmounting any hard substance, and the wheels descending with great force tend, by repeated blows, to wear holes in the surface, even on roads maintained with the hardest material. By the carriage being

mounted on springs, the power required to draw a vehicle over an obstacle of this kind is lessened, and the damage to the surface of the road is also greatly reduced.

(3) *Gravity.*—When a road is on an incline, the additional influence due to gravity, which is proportionate to the steepness of the gradient, must be allowed for in arriving at the greatest tractive force which the prime mover is capable of exerting. The resistance due to gravity on an incline is found approximately by dividing the number of pounds in a ton by the rate of inclination.

(4) *Air Resistance.*—This varies according to the velocity of the wind the area of the surface acted upon, the velocity of the vehicle, and the angle or direction at which it impinges against the plane of the surface. At a velocity of 15 miles an hour, equivalent to a pleasant breeze, the force of the wind is equal to 1·107 lbs. per square foot, while at a velocity of 50 miles an hour, amounting to a violent storm, the force is equal to 12·30 lbs. per square foot of surface.

2. **Tractive Force.**—The power required to move vehicles along a road depends on, and varies greatly according to, the condition of the surface of the road. The force or pull which a horse has to exert to draw a load on a level macadamized road in ordinary repair may be taken at $\frac{1}{30}$ of the load, but may vary from $\frac{1}{48}$ of the load on roads in the best condition to $\frac{1}{25}$ on roads the surface of which is badly maintained, and broken by ruts and hollows.

Authorities, however, differ widely on the subject of the tractive power of the horse, and this will be obvious when the varying diameters of wheels of vehicles and the strength and speed of different animals are taken into consideration, along with their adaptability or training for any particular class of work.

TABLE I.

Materials.	Resistance to Traction on Level.	Tractive Force in lbs. required to move one ton on a Level. A.
Asphalted roadway,	1·0	15
Paved roadway, dry and in good order,	1·5 to 2·00	22·5 to 30·0
,, ,, in fair order,	2·0 to 2·5	30·0 to 37·5
,, ,, but covered with mud.	2·0 to 2·7	30·0 to 40·5
Macadamized roadway, dry and in good order,	2·5 to 3·0	37·5 to 45·0
,, ,, in a wet state,	3·3	49·5
,, ,, in fair order,	4·5	67·5
,, ,, but covered with mud,	5·5	82·5
,, ,, covered with loose stones.	5·0 to 8·2	75·0 to 123·0

The figures in Table I. are now generally adopted in arriving at the relative tractive force necessary to draw a load on different kinds of material composing a road surface.* Asphalt is taken as the standard of excellence, and in the extended part of table, under A, 15 lbs. is allowed for the force necessary to draw one ton on a level on that class of road.

On a macadamized road maintained in excellent order the table shows that the force put forth by the prime mover is 45 lbs. per ton, or a tractive force exerted of $\frac{1}{50}$ of the gross load. On a road which is only in fair order, slightly cupped, or has an irregular surface, the tractive force exerted rises to $\frac{1}{33}$ of the gross load, while on a road having the surface covered with loose stones the draught or tractive force necessary to be put forth amounts to, at its worst, $\frac{1}{18}$ of the gross load.

3. The following are the general results of the experiments made by M. Morin upon the resistance of the traction of vehicles on common roads:—

1st. The resistance to traction is directly proportional to the load, and inversely proportional to the diameter of the wheel.

2nd. Upon a paved or a hard macadamized road the resistance is independent of the width of the tyre, when this quantity exceeds from 3 to 4 inches.

3rd. At a walking pace, the resistance to traction is the same, under the same circumstances, for carriages with springs and for carriages without springs.

4th. Upon hard macadamized roads and upon paved roads, the resistance to traction increases with the velocity—the increments of traction being directly proportional to the increments of velocity above the velocity 3·28 feet per second, or about 2¼ miles per hour. The equal increments of traction thus due to equal increments of velocity are less as the road is smoother, and as the carriage is less rigid or better hung.

5th. Upon soft roads, of earth, or sand, or turf, or roads fresh and thickly gravelled, the resistance to traction is independent of the velocity.

6th. Upon a well-made and compact pavement of hewn stones, the resistance to traction at a walking pace is not more than three-fourths of the resistance upon the best macadamized roads, under similar circumstances. At a trotting pace, the resistances are equal.

7th. The destruction of the road is, in all cases, greater as the diameters of the wheels are less, and it is greater in carriages without than in those with springs.

4. Experiments were carried out by Sir J. Macneil on the road between London and Shrewsbury to ascertain the tractive forces required there, and measured by an instrument devised by him for the purpose. The general results, reduced to that on a level, as given by Telford,† are presented in Table II.

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* Vide *Report of the Society of Arts on the application of Science and Art to Street Paving and Street Cleansing of the Metropolis*, 1875.

† *Seventh Report*, etc., p. 13.

TABLE II.

Description of Road.	Tractive Force per Ton.	Angle of Repose Represented.
Draught on a well-made pavement, . . .	33 lbs.	$\frac{1}{68}$
„ broken stone surface on old flint road	65 „	$\frac{1}{35}$
„ gravel road, ...	147 „	$\frac{1}{15}$
„ broken stone road upon a rough pavement foundation, ...	46 „	$\frac{1}{49}$
„ broken stone surface on a bottoming of concrete, ...	46 „	$\frac{1}{49}$

5. It appears from experiments carried out at the Royal Agricultural Show at Bedford in 1874, by means of a horse dynamometer, made by Messrs. Easton & Anderson, that 1 lb. of draught was expended on moving every 35·1 lbs. of weight resting on a wagon with fore wheels of 41 inches in diameter, while on the hind wheels having a diameter of 60 inches it was 58·7 lbs. In the former case it was thus equal to a tractive force of 64 lbs. per ton with the smaller size of wheel, compared with 38 lbs. for that of the larger one, which latter figure practically agrees with those in the above table. Of the other trials at the same place with loaded wagons, having tires 2½ to 4½ inches wide, the average draught was $\frac{1}{49}$ of the gross load, or nearly 46 lbs. per ton. For single horse carts, loaded to about 30 cwt., the wheels of which were from 52 to 62 inches in diameter, and the tires 3½ to 4 inches wide, the tractive force was found to be on a level macadamized road at a walking pace $\frac{1}{65}$ of the gross load, or 34½ lbs. per ton. With other carts having wheels of slightly larger diameter and a greater load, the average draught under similar conditions was found to be $\frac{1}{51}$ of the gross load, or 44 lbs. per ton.

6. There can be no question that the smoother and harder the surface of a road is, the tractive force or draught necessary to move a vehicle will be less. It must also be apparent that the work of one horse on a level and well maintained road, may be easily increased two or three times, if the surface of the road is inferior in condition, by reason of any inequalities or ruts on the surface. In other words, four horses are enabled to do the work of five, or three of four, by keeping the roads in an efficient state of repair.

7. Gradients.—In ascending an incline the prime mover has to exert an additional force which has to be added to that of resistance on the level. This is approximately equal to the gross load divided by the rate of gradient. It can be shown diagrammatically what additional resistance is occasioned when the road is inclined against the load instead of being level.

In the accompanying diagram fig. 7, the whole weight is supposed to be supported on one pair of wheels, being the simplest form in which this additional resistance may be investigated, and which can be shown in the following manner.

Let AB represent a part of an inclined road, D a vehicle sustained in its position by a force acting in the direction DG, DW the weight of the vehicle and load or the force of gravity acting vertically downwards. It is evident that the vehicle is sustained in equilibrium upon the inclined plane by these two forces, and, in addition, by the resistance of the road surface to the pressure of the vehicle acting at right angles to the incline of the road. To determine the relative magnitude of these three forces, draw the horizontal line BC and the vertical line AC; then since the two lines DE and AC are parallel and are both cut by the line AB, it follows that they must make the two angles DEF and BAC equal; likewise, the two angles DFE and ACB are equal; therefore, the remaining angles EDF and ABC are equal, and the two triangles DEF and BAC are similar. As the three sides of the former are proportional to the three forces by which the vehicle is sustained in equilibrium, so also are the three sides of the latter; viz., AB or the length of the road is proportional to W, or the weight of the vehicle and its load; AC or the vertical rise is the same to E, or the force required to sustain the vehicle on the inclined plane; and BC or the horizontal distance in which the rise occurs, to P, or the force with which the vehicle presses upon the surface of the road.

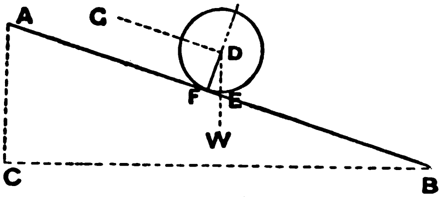

Fig. 7.

Therefore W : AB :: E : AC
and W : AB :: P : BC

And if BC be of such a length that the vertical rise AC of the road equals one foot, then the force DG will be represented by

$$\frac{W}{AB} = \frac{W}{\sqrt{BC^2+1}} = W \sin B$$

and

$$P = \frac{W.BC}{AB} = \frac{W.BC}{\sqrt{BC^2+1}} = W \cos B$$

in which B is the angle ABC.

These formulæ reduced to words are as follows:—

To find the force requisite to sustain a vehicle upon an inclined road, the effects of friction being neglected, divide the weight of the vehicle and its load by the inclined length of the road, the vertical rise of which is one foot, and the quotient is the force required.

To find the pressure of a vehicle against the surface of an inclined road, multiply the weight of the loaded vehicle by the horizontal length of the road, and divide the product by the inclined length of the same; the quotient is the pressure required.

The force with which a vehicle presses upon an inclined road is always less than its actual weight; the difference is so small, however, that on roads with a moderate inclination it may be taken as equal to the weight of the loaded vehicle.

To find the resistance to traction in passing up or down an incline, ascertain the resistance on a level road having the same surface as the incline, to which add if the vehicle ascends, or subtract if it descends, the force requisite to sustain it on the incline; the sum or difference, as the case may be, will express the resistance. The tractive power of horses varies according to their strength, speed, and the adaptability and training which they possess for any particular kind of work. An average horse will, travelling at a speed of 2½ miles an hour, exert a pull of 110 to 120 lbs. on a level road with a smooth surface; while at a speed of 4 miles an hour, the draught exerted will only amount to from 65 to 75 lbs.

The tractive power of a horse becomes less as the speed increases, while in ascending inclines its power diminishes rapidly, a considerable portion of its strength, due to its own weight and that of the load, is expended in overcoming the resistance of gravity.

In ascending a perfectly smooth road, the amount of foothold afforded being less, tells more against the draught of a horse than one of ordinary roughness. The extreme comparisons may be taken as asphalt and macadam.

8. It is interesting to note that a horse is as strong as five men on a level, while on a gradient of 1 in 6 its tractive power is barely equal to that of three men.

Table III. shows the decrease in the loads in ascending gradients.

A horse can, however, exert for short distances twice to three times the average tractive power which he is capable of exerting continuously during a day's work, so that if the resistance on the gradient be not greater than double or three times the resistance on the level, the horse will be able to ascend such inclines with the gross load he is capable of drawing under ordinary conditions.

9. Professor Mahan deduced, from the results of experiments on tractional resistance carried out by Sir John Macneil, that the angle of repose is represented by the fractional part of the weight of the carriage, which, when applied to it, would be just sufficient to overcome the friction, and set the carriage in motion. In other words, the angle of repose for a well-made pavement would be represented, taking one ton or 2240 pounds as the load moved, as $\frac{33}{2240}$ or $\frac{1}{68}$ nearly, and the gradient for this class of road should not be greater than 1 in 68, or 1 perpendicular to 68 horizontal.

For the values of the angle of repose or the greatest inclination which should be given to a road made with different descriptions of material, see Table II. page 31.

TABLE III.

Effects of Gradients upon the Loads which a Horse can draw on a Macadamized Road, the Load on the Level being taken as represented by 1.

Inclination.	Angle.	Rise in feet per mile.	A horse can draw	Inclination.	Angle.	Rise in feet per mile.	A horse can draw	Inclination.	Angle.	Rise in feet per mile.	A horse can draw
	° ′				° ′				° ′		
1 in 10	5 43	528	·25	1 in 15	3 49	352	·325	1 in 20	2 52	264	·4
1 in 11	5 11	480	·265	1 in 16	3 35	330	·34	1 in 24	2 23	220	·5
1 in 12	4 46	440	·28	1 in 17	3 22	310	·355	1 in 25	2 18	211	·52
1 in 13	4 24	406	·295	1 in 18	3 11	293	·37	1 in 26	2 15	203	·54
1 in 14	4 5	337	·31	1 in 19	3 0	277	·385	1 in 30	1 55	176	·64

It is very desirable that in all cases the gradients should be reduced as much as practicable, as the extra exertion necessary to be expended by a horse in ascending steep gradients is considerable, and adds greatly to the cost of haulage.

Sir John Macneil, in 1836, maintained that no road was perfect unless its gradients were equal to, or less than, 1 in 40. M. Dumas, engineer-in-chief of the French Ponts et Chaussées, writing in 1843, recommended 1 in 50 as a maximum rate of inclination; whilst Professor Mahan considered, as a general rule, that gradients should be kept as low as 1 in 33. M. Dupuit recommends for the maximum gradient for metalled roads a 3 per cent. incline, or 1 in 33, and for pavements a 2 per cent. gradient, or 1 in 50. The gradient of 1 in 30 adopted by Telford is such that, in ascending it, a horse can easily put forth the force necessary over and above the pull needed for taking the load along the level. Gradients of 1 in 20, and even steeper, have at times to be introduced at points in the line of a proposed road, to obviate heavy expenditure in the construction of the works. On the other hand, a road should not be constructed on a 'dead-level,' but have a minimum gradient. This, although applying in a certain degree to traction, has reference more particularly to the maintenance of roads, and will, therefore, be treated in its proper place.

10. Wheels and Weights on them.—The imperfect condition of the roads at the beginning of the last century was such that regulations were embraced in the Acts relating to highways, enforcing that wheels of vehicles should be of great width in proportion to the weights carried. Table IV. gives these particulars.

TABLE IV.

Weight, Horse-power, and Wheels of Vehicles on Common Roads, 1809.

Breadth of Wheel.	Gross Weight.	Number of Horses.	Draught of each Horse.		Weight on the road at each Wheel.	Pressure per inch of Width.	
Inches.	Tons.		Cwt.	lbs.	Cwt.	Lbs.	Cwt.
16, . . .	8	10	16	0	40	280	2·50
9, rolling 16,[*] .	6½	8	16	42	32½	404	3·60
9, . . .	6	8	15	0	30	373	3·33
6, rolling 11, .	5½	6	18	37	27½	513	4·58
6, . . .	4½	6	16	0	22½	420	3·75
3, . . .	3½	4	17	56	17½	653	5·85
2, Stage Coach, .	4	4	20	0	20	1120	10·00

From the foregoing table, it is apparent that the pressure per inch of width of tyres at the surface of the road increases as the width diminishes. It was the opinion of practical men using the roads during that period, that a pressure of 4 cwt., or 448 lbs., per inch of width should not be exceeded; while the tyre of the wheel should be limited to a minimum width of 4½ inches. Unquestionably a tyre of moderate width, provided the weight distributed over it is not excessive, may be looked upon as one to be recommended.

11. Conical Wheels.—The excessively wide rounded tyres and conical shape of the wheel in use in the early part of the last century would appear to be the worst combination that could possibly exist. It is apparent that a conical wheel can only be made to travel in a straight line by a constant twisting action at the surface of the road. Consequently, the wider the tyre, the greater is the twisting and disintegrating action by the wheels on the material composing the crust of a road. The cylindrical wheel, with flat tyres of moderate breadth, is the best possible form for easy traction, and by its use less wear is occasioned to the road-surface.

The practical advantage in the dished or slightly conical form of wheel is that a wider space is afforded for the body of the vehicle, and the inclined spokes forming this class of wheel tend to resist the lateral shocks to which they are subjected at times. Although the cylindrical wheel was strongly advocated, and encouraged by many turnpike trusts, in the form of a reduction of tolls, still the dished or conical form of wheel has become almost of general use. Provided this class of wheel has a flat or but slightly rounded tyre, 4½ inches in breadth, little can be said against its use.

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[*] The rolling widths are the slant widths of conical wheels.

12. The General Turnpike Act (1823) regulated the weights to be carried by wagons, carts, etc., with wheels having tyres varying from 4½ to 9 inches in breadth, the weights allowed being generally 10 cwt. less in winter than those carried during the summer months. Wheels having tyres of a less width than 4½ inches were not so restricted. Consequently, it was possible to carry with tyres 2½ inches in breadth the same weight as was allowed for wheels having tyres 4½ inches in width. The extra toll imposed on carts with narrow tyres did not, however, prevent their use, and after the tolls were abolished they became general, and are now to be found on far the greater proportion of vehicles travelling on the highways.

Sir J. Macneil, in his evidence before the Committee on Steam Carriages in 1831, gave the following particulars as to weights of coaches and wagons, and the pressure per inch of width of tyre.*

TABLE V.

Description of Vehicle.	Weight on the Average.	Breadth of Wheel.	Pressure of each Wheel.	Pressure on each inch of Breadth.
Mail Coach, . . .	2 tons	2¼ inches	10·0 cwt.	4·40 cwt.
Stage Coach, . . .	2½ ,,	2 ,,	12·5 ,,	6·25 ,,
Van, ...	4½ ,,	2½ ,,	21·25 ,,	8·29 ,,
Wagon, ...	6 ,,	9 ,,	30·0 ,,	3·33 ,,
,, ...	4½ ,,	6 ,,	22·5 ,,	3·75 ,,
,, ...	3½ ,,	4 ,,	17·5 ,,	4·37 ,,

It will be observed that the weight per inch of tyre is exceedingly high for vans as compared with wagons, the tyres of which were 9 inches in width. As the edges of narrow tyres become rounded through wear, it is evident that the pressure per inch of width will in time become greater than that tabulated, even to the extent of 25 per cent.

13. The Acts relating to the weights allowed for wheels with tyres of different width having been repealed, County Authorities were empowered to make by-laws, under the Highways and Locomotives Act of 1878, for regulating the width of wheels in relation to the weight carried. In those counties where such powers have been exercised, the practice usually followed was to adopt the weights allowed under the General Turnpike Act, with any modification which was considered necessary for the varying conditions in different parts of the country.

14. The weights on wheels under the different conditions to which roads are now subjected vary considerably, according to circumstances, as may be gathered from the following, bearing more particularly on the effect produced by vehicles having wheels with wide tyres.

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* *Evidence, Committee on Steam Carriages*, p. 95.

It is a difficult matter to conceive how it is possible that a rigid wheel with a tyre having a breadth of 18 inches can bear equally on the surface of a road for that width. From the manner in which these wheels are constructed they present a rigid flat surface, and this has to travel on a road having a transverse surface convex in form. The amount of convexity varies according to circumstances, and in the form least necessary for surface drainage it presents the part of a circle, or by two inclined straight lines from either side joined by a curve in the centre. Under these circumstances the point of contact of the wheels on the road-surface will be confined, theoretically, to a single point which is the inner edge of the tire. The rise generally given to a road-surface transversely is such that with tires of moderate width the pressure is uniform over the full width, but in the case of vehicles having tires of great width a portion only of the breadth transmits the whole weight to the surface of the road.

Macadam gave it as his opinion, in his evidence before the Select Committee on Steam Carriages, 1831, that no advantage was gained by increasing the breadth of the tyre above 4½ inches, as a greater breadth could not at one time touch the surface of a well-formed road. Similar results were obtained by Morin from actual experiments carried out with vehicles having wheels with cylindrical tyres of 2·5 inches, 4·6 inches, and 7 inches in width, respectively. These results, concisely stated, showed that over 30 per cent. more tonnage can be carried over a road in good order, on wheels having tyres 4½ inches wide, than can be done on wheels with tyres 2½ inches wide; the wear or damage resulting to the surface of the road being about the same in each case. It was also observed that any excess of width of tires beyond that stated had no compensating value.

15. It would appear from these conclusions that wheels of wagons and other vehicles having tyres of from 6 to 9 inches in breadth, traction-engines with rigid tyres having a width of from 15 to 18 inches, and the driving or hind wheels of steam road-rollers with rims 18 to 20 inches wide, are powerful agents in destroying the crust of a road. In the case, however, of wagon wheels with tyres beyond 4½ inches in breadth, as also the driving-wheels of steam road-rollers, this want of equal bearing surface, owing to their rigid construction, is found not to apply after they have been in use for some time. The inside edges of these wheels for a time carry practically all the weight, but in time they conform through wear, especially in the case of rollers, to the transverse convexity of the road surface.

16. **Traction-Engine Wheel Tyres.**—In traction- or road-engines having the ordinary rigid tyres, with diagonal bars at the periphery, this wearing away or conforming to the section of the road does not take place, or at least to a very limited extent. In the nature of the work of these engines travelling over all conditions of roads in an indifferent state of repair, the flat form of the tyre practically remains unaltered, except, pro-

bably, the edges get somewhat rounded. This rounding still reduces the bearing-surface, in some cases by 3½ inches, even should it bear equally in the case of a road of which the surface is considerably worn, and consequently flat transversely.

TABLE VI.

Showing Weights carried by various Vehicles under varying conditions.

Description of Vehicles.	Width of Tyre.	Load on Wheel.	Load per inch of Width of Tyre.
	Inches.	Cwt.	Cwt.
Traction-Engine weighing 12 tons in steam, two-thirds of weight on driving-wheels, and bearing equally throughout their width, ...	18	80	4·44
Traction-Engine, with a bearing-surface of 50 per cent. of actual width of wheel, .	18–9	80	8·88
Traction-Engine, with a bearing-surface of 25 per cent. of actual width of wheel, .	18–4½	80	17·76
Traction-Engine weighing 9 tons in steam, two-thirds of weight on driving-wheels, and bearing equally throughout their width, ...	16	60	3·75
Traction-Engine, with a bearing-surface of 50 per cent. of actual width of wheel, .	16–8	60	7·50
Traction Engine, with a bearing-surface of 25 per cent. of actual width of wheel, .	16–4	60	15·00
Steam Road-Roller, with scarifier attached, weighing 16¼ tons in steam, three-fifths of weight on driving-wheels, 6 ft. in dia.,	18	97·50	5·42
Steam Road-Roller, do. do. .	20	97·50	4·88
Heavy Motor Car, with 5 feet 6 inches driving-wheels, ...	8	80	10·0
Wagon for Steam Traction, weight 30 cwt., load 6 tons, bearing equally on tyre throughout the full width, . . .	8	37·5	4·69
Wagon for Steam Traction, with bearing-surface of 56 per cent. of actual width of wheel, ...	8–4½	37·5	8·33
Wagon for Steam Traction, weight 28 cwt., load 4 tons, bearing equally on tyres throughout the full width, . . .	6	27	4·50
Wagon for Steam Traction, with bearing surface of 78 per cent. of actual width, .	6–4½	27	6·00
Wagon for Steam Traction, weight 25 cwt., load 3 tons, ...	4	21·25	5·31
Horse Wagon, weight 21 cwt., load 2 tons,	2	15·25	7·62
Cart, weight 9 cwt., load 35 cwt., . .	4	22	5·5
Cart, weight 9 cwt., load 31 cwt , . .	2½	20	8·0

From the above it follows that the bearing-surface at the point of contact between the wheel and the road is reduced to one-half, and sometimes even less, on a road having the surface properly formed transversely. On a road well worn or comparatively flat, the pressure will be distributed over a greater surface, and in the event of such surface being worn so that it forms a level transversely, then, and then only, can the full width of the wheel bear equally on the road. It need hardly be pointed out that the surface of a road under such conditions is in a state of disrepair, when it cannot be expected to bear even the distributed weight which such conditions make possible.

Table VI. illustrates very forcibly the conclusions arrived at in the preceding paragraphs.

The effect, on the surface of a road, of the passage of a traction-engine, during and immediately after a fall of rain, when the surface is slightly covered with mud, clearly proves the foregoing statements. On a flat transverse surface the full width of the wheel tyre is clearly defined; on a road having only a moderate curvature, the extent of the impression caused by the passage of the engine wheels may vary from 75 per cent. to 50 per cent. of their actual width of tyre; while on a road with a transverse curvature or convexity according to present practice, an impression of not much more than 25 per cent. of the actual width of the wheel tyre is visible on the surface of the road.

It is evident, therefore, that in the case of a traction-engine, the wheels of which only touch the road surface for 4½ inches of their width, a very heavy strain is imposed on the material comprising the road covering. During dry weather this excessive weight causes a considerable amount of abrasion of the material at the surface of the road. When thaw succeeds frost, and the immediate surface of the road coating is in a somewhat loose state, the passage of traction-engines has the effect of greatly disturbing the materials of the road-crust on roads generally, and is extremely trying even on those which are repaired with the best possible class of macadam and maintained in the best condition. It often happens, after alternating frost and thaw, that the road coating is affected to a greater or less depth; and at such times the passage of a traction-engine over a road causes considerable damage by crushing the stones comprising the coating, and in many instances lifting and displacing patches of the material.

17. Vehicles with Narrow Wheels.—Vehicles with narrow wheels carrying heavy loads cause much damage under similar conditions, particularly on a road where, with but little passing traffic to cause the vehicles to follow a zigzag course and change their position, they run in tracks and form hollows in the surface. The increased cost of maintaining roads under these circumstances clearly points to the necessity of having improved tires for vehicles, or of adopting more stringent measures for regulating such traffic under the adverse conditions alluded to.

18. Improvement of Traction-Engine Wheel Tyres.—More particularly in the case of traction-engines does the necessity exist for some form of flexible driving-wheels which would, by the construction of the tyres, distribute the weight in a uniform manner over the actual width of wheel, and at the same time minimize vibration, which in the ordinary traction-engine causes considerable damage to buildings situated near the road traversed.

Attempts have been made from time to time to attain this object, and while in many cases the vibration has been considerably reduced, the rigid tyre has always been conspicuous by its presence.

Boulton's flexible wheel, patented some years ago, has supplied in a great measure the requirements so necessary for the effective distribution of the weight to the surface of the road, and the elimination of vibration.

The description of this wheel, or rather the tyre, may be briefly stated as follows:—The driving-wheel is 7 feet in diameter and 16 inches wide. The periphery of the wheel consists of a deep rim divided into sixty-eight cells or compartments, two in the width of tire and breaking joint with each other. Into these cells, which are about 6½ inches square and 9 inches deep, hardwood blocks are fitted, with an allowance for a suitable amount of radial play. Each block, with the grain of the wood pointing outwards, is bound round, near the lower end, with an iron band. The blocks rest on an indiarubber cushion 5½ inches square and 1 inch thick, or some other elastic material sufficiently yielding to absorb the jar while working. The blocks are attached to the inner rim of the tyre by a bolt let into the wood block several inches; it then passes through the elastic pad and inner rim, and is secured by a nut. The recess at outer end of block is fitted with a wood plug. As the wheel revolves, the weight comes on three, four, or five blocks, the indiarubber pads are compressed while the bolts work freely in the slot of the inner rim, and the blocks adapt themselves to the surface of the road.

With this class of tyre it is evident that, as four or more of these hardwood blocks bear on the road surface at the same time, the weight is distributed both transversely and longitudinally. By this arrangement the pressure on the road is considerably reduced, the weight being spread over a considerable area. In the case of a traction-engine weighing 12 tons, the pressure with three blocks in contact with the road surface only amounts to a little over ½ cwt. per square inch.

It will be readily understood that, apart from doing any damage to the road surface, the engine is much more efficient, especially when ascending steep gradients, by reason of the increased contact surface afforded by the wood blocks.

19. Excessive Weights on Wheels.—Heavy weights carried on vehicles with narrower tyres than 4½ inches cause considerable wear even on a hard dry road, and, as has been pointed out, the damaging effect during alternating frost and thaw is a very serious matter. The proper width of tyre, or proper load upon any vehicle for a given width of tyre, is a question which deserves more attention than is usually accorded to it.

The by-laws controlling the weights to be carried on wheels should certainly restrict these weights to about 5 cwt. per inch of actual bearing surface on vehicles without springs. This pressure is almost similar to that exerted by a 15-ton road roller which makes the road for the traffic. If the weight carried on the tyres of any description of vehicle were not to exceed this standard, infinitely less damage would result to the road surface, and a corresponding decrease in the cost of maintenance would be effected. Vehicles in a state of disrepair, such as those having a slightly bent axle or an excessive play between the nave and axle, aggravate the evil, and also create an additional burden on the horses drawing the vehicles.

Sir J. Macneil stated before the Committee on Steam Carriages in 1831 that, from his experience on the road between London and Shrewsbury, he considered a wheel should have a tyre an inch in width for every 5 cwt. of load. Telford was of opinion that the weight should not exceed 1 ton upon each wheel; while Macadam, speaking from his experience of the Metropolitan roads, considered that the maximum load should not exceed 9 cwt. per inch of width of tyre. This latter weight is undoubtedly too much for roads even in first-class repair.

20. Effect of Springs on Vehicles.—Experiments have shown that vehicles on springs diminish the wear of roads, especially at speeds beyond a walking pace. Going at a trot, they were found not to cause more wear than vehicles without springs at a walk, all other conditions being similar. Vehicles with springs improperly fixed cause considerable concussion, which in its turn destroys the road coating. If the surface of the road be irregular, there is increased draught, and this also means additional wear by the horses' feet.

The size of a wheel has also an important bearing on the wearing of roads, a wheel of small diameter causing relatively much more wear than one of large diameter. Wheels of the common size, or about 6 feet in diameter, are considered best; they also reduce the draught for the horses.

In regard to the above-mentioned conditions it may be stated that in connection with the provisions of the "Heavy Motor Car Order" (1904) recently issued by the Local Government Board, these important factors have been given effect to in respect that the unit weight per inch width of tyre is dependent on the size of wheel and axle-weight. It is also provided that suitable and sufficient springs shall be fixed between the axle and frame in both motor cars and trailers.

21. The main features of these regulations may be stated as follows. Certain rules are to be observed as regards the width of tyres of heavy motor cars and trailers having ordinary tyres. The regulations do not, however, apply to any vehicle having tyres which are pneumatic or which are of a soft or elastic material. The minimum width of tyre allowed is 5 inches for a heavy motor car, and 3 inches for a trailer exceeding one ton in weight unladen. The actual width of tyre required for any particular

diameter of wheel is fixed by a varying scale, depending on the diameter of wheel and the registered axle-weight.

The total axle-weights of a heavy motor car, including load, is limited to 12 tons, and the weight borne on any axle is not to exceed 8 tons. In the case of trailers, the axle-weight is limited to 4 tons. The speed of a heavy motor car may vary from five to twelve miles per hour, depending on the weight carried, if used with a trailer, or if the tyres are pneumatic.

The following Table (VII.) is an abstract from the Regulations as to Heavy Motor Cars (1904), the first and last prescribed weights and widths in each case only being given. The intermediate figures can be obtained by calculation from the unit of axle-weight to be carried or from the width of the driving wheels as the case may be.

TABLE VII.

Heavy Motor Car Order, 1904.

Diameter of Wheels.		Unit of Registered Axle-Weight.	Heavy Motor Cars (Axle-Weight).		Trailers (Axle-Weight).		Width of Tyres.	
							Heavy Motor Cars.	Trailers.
Feet.	Inches.	Cwts.	Not exceeding Tons.	Cwts.	Not exceeding Tons.	Cwts.	Inches.	Inches.
2	0	5½	2	15	1	13	5	3
,,		,,	8	0	4	0	15	7½
2	3	6	3	0	1	16	5	3
,,		,,	8	0	4	0	13½	7
2	6	6½	3	5	1	19	5	3
,,		,,	8	0	4	0	12½	6½
2	9	7	3	10	2	2	5	3
,,		,,	8	0	4	0	11½	6
3	0	7½	3	15	2	5	5	3
,,		,,	8	0	4	0	11	5½
3	3	7¾	3	17½	2	6½	5	3
,,		,,	8	0	4	0	10½	5½
3	6	8	4	0	2	8	5	3
,,		,,	8	0	4	0	10	5
3	9	8¼	4	2½	2	9½	5	3
,,		,,	8	0	4	0	10	5
4	0	8½	4	5	2	11	5	3
,,		,,	8	0	4	0	9½	5
4	3	8¾	4	7½	2	12½	5	3
,,		,,	8	0	4	0	9½	5
4	6	9	4	10	2	14	5	3
,,		,,	8	0	4	0	9	4½
4	9	9¼	4	12½	2	15½	5	3
,,		,,	8	0	4	0	9	4½
5	0	9½	4	15	2	17	5	3
,,		,,	8	0	4	0	8½	4½
5	3	9¾	4	17½	2	18½	5	3
,,		,,	8	0	4	0	8½	4½
5	6	10	5	0	3	0	5	3
,,		,,	8	0	4	0	8	4

It may be mentioned that the "unit of registered axle weight" in each case appears to be intended for the hind or driving-wheels, that in the fore or steering wheels being considerably less. This is advantageous in many respects to the maintenance of macadamized roads.

22. On roads which have been newly coated and steam rolled, the contour is made with a reasonably good rise to assist the surface drainage, in which case, as already pointed out, wheels exceeding 4½ to 6 inches do not bear equally over their whole width. On roads the surface of which has worn down in a regular manner, the bearing surface may be 8 to 9 inches, and any width beyond this does not appear to have any compensating benefits so far as the road is concerned. The unit of weight will therefore in many instances be greater than that specified in the "Order."

It will be observed that for wheels 5½ feet in diameter a unit weight of 10 cwts. is allowed per inch width of wheel. This is nearly twice as much weight per unit of width as that exerted by a 15-ton roller having approximately the same diameter of wheel in consolidating macadamized roads, and clearly points out that, should these vehicles come into general use, as is anticipated, the roads will have to be materially strengthened to accommodate this traffic. The effect of springs being introduced between the axle and frame no doubt lessens the concussion inseparable from these road engines and wagons of rigid construction. These weights nevertheless appear excessive for roads of ordinary construction, but as these vehicles have been introduced with the intention of promoting cheap transport, it follows that improved road construction must be undertaken. This matter will be treated more fully in Chapter VII. on Road Rolling.

23. The investigations which are being carried out by a committee of the British Association on the Resistance of Road Vehicles to Traction embody most interesting and valuable information on this subject. The results are contained in the Reports issued by this Association, and are given here as an appendix.* The results of the earlier experimenters, which are given in the preceding pages, and which are embraced in the "Reports" referred to and prepared by Dr Hele-Shaw, contain also much additional information presented in a very concise and instructive manner.

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* For the Report of the British Association for Advancement of Science on the "Resistance of Road Vehicles to Traction," see Appendix I.

CHAPTER II.

LAYING OUT NEW ROADS, AND THE IMPROVEMENT OF EXISTING LINES OF COMMUNICATION.

THE selection or location of country roads is carried out by making an examination or reconnaissance of the tract of country to be traversed, so as to obtain the requisite data for the purpose of determining the best route and gradients for the proposed line of communication.

24. The most direct or shortest practicable route between two points at once suggests itself; but this, in every case, must be governed by the natural features of the surface of the country. The object aimed at is to ascertain the most favourable direction in which to lay out a road, so as to convey the traffic with the least expenditure of motive power consistent with reasonable economy in construction and in the subsequent maintenance of the road and works.

25. "Economy of motive power is promoted by low summit-levels, flat *gradients* (as the rates of declivity of lines of land-carriage are called), easy curves, and a direct line; but limitations to the height of summits, the steepness of gradients, and the sharpness of curves, limit also the power of adapting the line to the inequalities of the ground, and so economizing works." *

In a thickly populated district the new line of communication is to a certain extent predetermined by the existence of towns and villages, while in a sparsely populated tract of country greater liberty in selecting the route to be followed is permissible, as the natural character of the country alone would form the basis for selection.

In either case the engineer, in laying out the line of a new road, must be governed by the principles laid down in the preceding chapter, in so far as the gradients are concerned.

26. Reconnaissance.—The general series of operations preliminary to the formation of a new line of communication are the examination or reconnaissance of the country between the points to be connected, taking note of the physical features of the country, its geological formation and sources from which materials for construction may be obtained, and the probable requirements of the district to be passed through. In this work the engineer will be greatly aided by obtaining the best and most reliable maps of the district. Flying-levels are generally taken concurrently, in order to ascertain the elevations of detached points, such as passes across ridges, and valleys, also points where structures of magnitude may be required.

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* Rankine's *Civil Engineering.*

27. General Principles to be observed in the Field.—In laying out a line for a new road, the following data should be carefully noted and recorded in the field-book:—

Examine the inclination of the strata, their nature and condition as to dryness.

Provide for the surface of road being exposed as much as possible to the action of the air and sun's rays.

Cross valleys, rivers, and passes at right angles.

Examine beds of rivers at proposed crossings and up and down stream, with a view to secure stable foundations for bridges, culverts, etc.

Examine sources, accesses, and distances of the supply of material for the erection of structural works, and for stones suitable for the road-covering.

Ascertain accurately the level of all existing lines of communication, such as railways, roads, canals, and of rivers and streams.

28. Method of selecting Final Route.—It is advisable, before finally fixing the direction which a new road may take, to lay out two or more trial lines in order that a comparison can be made and it may be seen which so far complies with the following requirements. One of the principal conditions which every line of communication should satisfy is that it connects the two points by the shortest practicable route consistent with flat gradients and economy of construction. A uniform gradient can always be obtained, when there is a continual rise of the ground from the point of departure and the point where the road crosses the ridge, in a serpentine course, by following the sinuous and irregular formation of the ground. It is necessary to join the straight portions of the line at the points of change of direction by curves, concave towards the hollows, and convex going round the projecting spurs of land. A return to the straight line is advisable, and should be given effect to at every opportunity. It is also essential that a uniform ascent be obtained between the two points which are to be connected, in order to avoid unnecessary ascents and descents, thus causing a loss of motive power. Long reaches of level, especially in cuttings, should be avoided, as they add to the difficulty of drainage, and to the subsequent cost of the maintenance of the road.

29. Roads in Mountainous Districts.—In very hilly districts the route may have to be formed in a zigzag fashion in order to maintain the 'maximum' gradient. It is advisable that the curved portions (which are generally somewhat abrupt), connecting the straight sections, should have the gradient reduced so as to conduce to the safety of vehicles descending. The gradients of roads may be classed into those suitable (1) for fast traffic; (2) for mixed traffic; and (3) for ordinary agricultural transit. The first will be best satisfied with maximum gradients of 1 in 50, the second with gradients of 1 in 30, and the third with gradients of 1 in 20. These gradients should, if possible, be strictly adhered to; but under certain conditions, the physical features of a district involving great expenditure in the construction of the works, gradients for short distances may be increased to 1 in 30 for fast traffic, and 1 in 15 for agricultural haulage. Marshy or very wet soils should be avoided, owing to the difficulty of obtaining a firm foundation for the road, and such places can only be made satisfactory by an effective system of drainage, the cost of which would, in most cases, greatly exceed the additional expenditure incurred by deviating from the proposed line, even though this should entail a considerable detour.

30. Topography.—As bearing upon the general information necessary to successfully lay out a line of communication, it is advisable, when exploring a district, to observe the following positions, which are of primary importance.

The physical features of a tract of country present an undulating and irregular formation, and endless varieties of forms and combinations. On close examination, however, two classes of lines or conditions of formation are perceived to exist, which go to make up the general form of the surface of the earth. These are called ridge-lines and valley-lines.

31. Ridge-Lines.—A ridge-line is distinguished by the property that along the whole of its course it is higher than the ground immediately adjacent to it on either side; it is seldom straight or level throughout any considerable part of its length, and is generally irregular both vertically and horizontally.

The lower points or depressions on a ridge-line are termed passes; the best point to cross a ridge is generally by one of the lowest passes.

32. Valley-Lines.—A valley-line, on the other hand, is distinguished by the property that along the whole of its course it is lower than the ground immediately adjacent to it on either side; or, in other words, the ground slopes upwards from it on both sides. Being the lowest point in the adjacent surroundings, the water on the surface of the ground necessarily flows towards the valley-line and, except when it is landlocked, runs along it in streams, sometimes called 'water-course lines.' Like a ridge-line, a valley-line is seldom level or straight throughout any considerable part of its length.

Rivers intersect the country in various directions, and between their point of discharge at the sea and the interior, the main or larger river is joined in its course by small ones or tributaries, which, in their turn, are joined by brooks and rills.

33. Maps.—Old maps or plans of a country showing the rivers and principal water-courses give a tolerably good idea of the direction of the valley-lines, while the Ordnance Maps of Britain, on the scale of six inches to one mile, show the principal contour-lines at every 50 feet of elevation in the flatter parts of the country, and at every 100 feet of elevation in the more hilly parts.

The latter are of great value to the engineer, as a means of enabling him to select the best line for the trial sections of a proposed line of road.

A projected road may be limited to the connecting of several points in the same valley, or it may have to connect points in two or more valleys. In the former case, the line of communication may be wholly situated on one side of the river or stream, which is the simplest case met with in practice. On the other hand, the points to be connected may be situated on the opposite sides of a valley and separated by a river; while in extreme cases, such as in a narrow valley, owing to the physical features of the ground, the line of the proposed road may have to be carried over the river or stream several times where the waterway cannot be deviated, or when a suitable line for the road cannot be obtained except by a deep rock-cutting or tunnel. In carrying out an extensive road system, it often happens that all the cases mentioned have to be dealt with, frequently perhaps, throughout its course.

34. When practicable, the line of road should be laid out on the driest ground available, and its position should be such that the surface is exposed to the joint action of sun and wind. Roads made in the lowest parts of a valley are subject to flooding, while those running along the side of a hill, especially where the strata dips towards the valley, are liable during and immediately after a storm of rain to suffer from land and earthwork slips, as well as surface-washings.

35. Longitudinal and Cross Sections.—In taking trial sections the method usually followed is to supplement the information by taking, at different points (especially where the surface of the ground is irregular) along the line or route, cross-sections of considerable length. This gives a good idea of the best direction which the centre-line of the intended road should follow in order to avoid, as much as possible, unnecessary cuttings and embankments.

In explanation of this, let A B, fig. 8, be a portion of the proposed road, and *c c* the breadth of country under consideration for this purpose. At any points along the line, depending on the changes of level of the surface of the ground, *s s*, contour-lines are measured off and fixed at right angles to

A B. These lines should be accurately levelled, and then drawn on the plan of the line of road.

The hatched lines show the form of the surface of the ground along the lines A B and *c c* on the plan, and there is no difficulty in seeing the extent of cutting and filling required, and in determining how the position of the intended line may be varied with reference to the natural surface of the ground, so that the cost of construction may be reduced to the smallest possible amount. When two or three trial sections are taken between the same points, the various lines should be compared in order to ascertain their relative advantages. If the centre-line be changed in position after due consideration of the foregoing, care should be exercised in laying down regular curves of proper radii to join the straight portions in the altered position of the line of road.

36. Laying Out Grade-Line in Hilly Districts.—Another method is sometimes followed when working in a gradient round the face of a hill in mountainous districts where the maximum gradient must be kept sight of continually. The lower portions of the hills in approaching valleys are generally flatter than those at and near the summit, and the line of road may be carried out in any desired direction which will be a continuation of the portion of road from the higher points. The proper course is to start the trial section from the pass at the summit and work downhill, the maximum gradient line being staked off, and the position afterwards surveyed and laid down on the plan, when any irregularities in the line may be corrected so as to show regular curves.

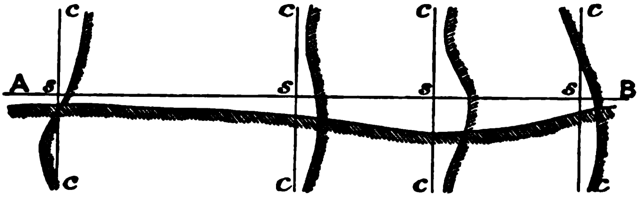


Fig. 8.—Trial sections.

Resting-places, or comparatively level stretches, are sometimes introduced when the gradients are steep and continuous: these should be provided at convenient intervals along the line of road.

37. Loss of Height.—In selecting the position for a proposed road, care should be exercised, as already pointed out, to avoid useless ascents as much as possible when a subsequent descent must be made, and the reverse, that is, introducing an intermediate rise in a descending gradient. An instance of this, owing to the manner in which the road was laid out with numerous and extensive useless ascents, has been noticed in the historical sketch, page 26.

38. Working Plans and Sections, Staking Out Centre-Line, Specifications and Estimates.—Subsequent to these preliminary operations, the survey for the working-plan is commenced, on which is delineated the centre-line of the intended road as finally fixed upon. The centre-line is then transferred on to the ground and pegs driven in at intervals, the end of the straight portions being indicated by two pegs. This operation is carried on until the whole length of road has been staked off, when the working-section is proceeded with.

This longitudinal section of the route is based on accurate levellings and measurements taken along the centre-line as staked out, and afterwards laid down on paper to suitable scales, with a horizontal line showing the datum, a line representing the surface of the ground, and lines marking the levels of the proposed work. The apex, or meeting-point of all gradients, should be rounded off by a vertical curve, as shown in fig. 9. Information as to depth of cuttings and height of embankments and other relative matter should be marked in figures on the section. Level-pegs, numbered from 0 upwards, are driven into the ground at regular distances of 100 to 300 feet, depending on the irregularity of the surface of the ground, cross-sections being taken at these and other intermediate points if necessary, and plotted on the longitudinal section to a natural scale. Bench-marks of a permanent nature should also be established at certain fixed points, such as near the site of a bridge or at a change of gradient. When this is accomplished, the detailed drawings of the various works embraced on the line of road can be completed, and the quantities of earthwork in the cuttings and embankments ascertained, when an estimate of the probable cost of constructing the road can be made with a certain degree of accuracy. To ensure greater precision, trial pits and borings are sometimes made with a view to ascertain the nature of the strata of which the ground is composed along the line of works, which information, apart from its immediate use in forming a correct estimate of the cost, should be marked on the plan and section for future reference.

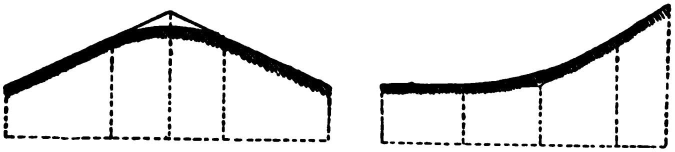


FIG. 9.

39. Intermediate Towns.—It will be a matter for consideration, in laying out a proposed new road between two distant points, whether or not the towns which are situated at some distance from the line of communication projected should be accommodated by branch roads striking off the direct road, so that all the towns and villages within reasonable distance may be put in mutual connection. Commercial considerations, well as the physical character of the ground, must govern this to a gr extent. Assume in the following instance that A and B, fig. 10, are t important towns which it is desired to connect with as direct a road, a with as easy gradients, as the nature of the intervening ground will adm of, and that at some distance from A there is, on one side of the direct lin an intermediate town C, where an industry, though limited, is carried o Examination, however, shows that the village C is situated at a consid ably higher elevation than the proposed road between A and the point D and onwards for some distance in the direction of B. This physic condition or difficulty would, if C were put in direct connection wit A and B, and indicated by the dotted lines A, C, E, practically conver what would otherwise be a well-laid-out road, having easy gradients, int one having steep inclines, necessitating a useless expenditure of moti power in transporting merchandise along what would then be the mai road if C were on the direct line. It is manifest, therefore, that the tow represented by C would be better accommodated, having regard to th traffic on the line of communication A B, by making a branch road C D.

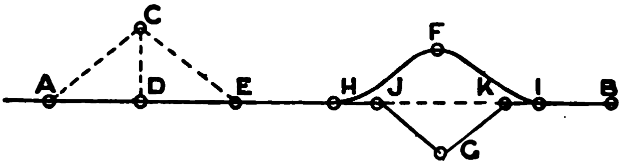


FIG. 10.

Further, in the direct line towards B there are two rising villages, F and G, from which a considerable prospective traffic is expected between the principal towns A and B, and *vice versa.* It is desirable that each should be situated so that the main road will pass through them, but it is apparent that this arrangement is impossible, as the detour, apart from any other consideration, would be very great, adding materially to the length of the main road.

Branch roads could be laid down at right angles to the main road, but the extra haulage, and consequent enhanced cost in the selling-price of goods, demands some consideration. Assume that the traffic from each of the points F and G will amount to about the same tonnage, therefore an equal claim, so far as traffic is concerned, exists in either case for direct communication. The physical character of the ground at and from these points in relation to the line A B will, however, decide which village should have the advantage of being placed on the main road. If it is found on examination, and after running trial-sections from the line A B to F and G, with a view to deviate the direct road, that the ground towards F is

practically the same as on the direct line, while at the point G it is somewhat lower, and the surface of the ground in the direction of J and K very irregular, it is quite clear through which village the main road should pass.

The route thus decided upon will therefore follow the letters A, D, E, H, F, and I to B. The point G may be connected by a line from there towards the main road A B at J or K, but as this would entail considerable extra haulage in a direction opposite to that in which the connecting road may be fixed upon, it is evident that this arrangement would affect the traffic from G to a considerable extent, and other means calculated to avoid this detour are obviously necessary.

This can be effected by laying down two branch roads G J and G K, and the point G may now be considered in as good a position in relation to the main road as the point F. It must be remembered, however, that the gradients, as has already been pointed out, from G to J and G to K are not so favourable to traction compared with the deviated part of the direct line H, F, I. The saving in transport on the shorter route will be proportionate to the tonnage carried, and assuming the distance saved to be one mile, it is evident that a saving of sixpence per ton at least would be effected on each ton of goods conveyed between these two points, which would represent a considerable sum of money per annum.

40. Laying out New Roads in actual practice. — In the following instance, taken from actual practice, the object in view was to lay out a new line of communication to connect two existing roads running nearly parallel, and at a distance of about 1½ miles from each other.

The existing roads are situated in separate valleys, with a hill or ridge intervening, and the only connection between them was formerly by a road having gradients at several points of 1 in 18, and at one or two points 1 in 10. By the construction of the new road a detour or saving in distance of 1¾ miles was effected.

The class of traffic to be accommodated consisted of fast and slow vehicles, in other words, mixed traffic, and a maximum gradient of 1 in 30 was therefore fixed upon as that fulfilling, under the circumstances, the conditions already laid down in this and the preceding chapter. Fig. 11, Plate I., shows the two existing and nearly parallel roads, A, B, C and D, E, F, while the cross road, which formed the only connection between these previous to making the new one, is shown at A D on plan. Owing to a continued and increasing traffic to and from the coast in a south-westerly direction, it was considered desirable to establish a more direct route, having gradients over which fast traffic could be conducted without much inconvenience to the prime mover. The first matter necessary to be determined was at what point the intended road should leave the existing one between A and C. Fig. 12 shows a longitudinal section of this road, and as the new road must necessarily start on a rising gradient, it is evident that the most suitable spot of departure is at B, because it is the highest point on the existing road. This point, therefore, was fixed on as the starting-place for the intended road. The point of arrival on the road D F had likewise to be determined, and on referring to a section of this road, fig. 12, it would appear the further east, or in the direction of D, the junction was made, that the gradients would be flatter. No doubt this is the case, but, on the other hand, this would to a certain extent defeat the object in constructing the new road, namely, that of as direct a route as possible. By going too far in the direction of F an unnecessary ascent would have to be overcome which would only make the new road longer without any compensating advantage.

The point E was therefore fixed upon as the termination of the intended road and junction with the existing one, D F.

The first consideration in laying out a new road being that of a direct route, a trial line may be drawn on plan, fig. 11, between the point of departure B and the terminal point E, in order to show, in this particular instance, that the shortest route must be subservient to that having suitable gradients. A section of the intervening ridge between the existing roads situated in the two different valleys, made from the contour lines on plan, clearly shows that such a route is impracticable, owing to the steep ascents and descents on either side of the ridge. This can generally be seen at a glance, as the steepest parts of the surface of the ground are at right angles to the contour lines. The route for the new road had therefore to be laid out along the slope of the hill in a direction tending towards E; and crossing the ridge at its lowest point or pass G, the line of road was then continued in a southerly direction to its termination at E.

On referring to the Ordnance Map, a reduced copy of which is shown in fig. 11, it will be observed that the summit level is 384·00 feet, while the height of the existing road at the point B is 134·00, or a difference of 250·00 feet. The approximate length of road between these points was ascertained to be about 8180 feet, giving a uniform gradient from B to G somewhat easier than 1 in 30. As this was the rate of inclination originally fixed upon, and as there would be no necessity under the circumstances to form a heavy embankment immediately south of the point B, where the ground is low, which would be the case if the maximum gradient were commenced from the existing road at that point, it was decided to lay out the portion from the point B for a distance of 289 yards with a gradient of 1 in 50.

The difference of level in comparison to the length of road also admitted, having regard to the maximum gradient fixed upon, of a short level stretch being introduced on the line of new road midway between the point B and the summit G.

The method followed in laying down the approximate route was to start from the fixed point G, and stake out the maximum gradient line, on the surface of the ground, down hill on the north side of the ridge. A somewhat similar process was carried out in fixing the direction of the line between the summit and the point E, being the lowest point of the valley at the stream, and requiring an embankment of considerable height.

The whole length of the proposed route was then surveyed, and the horizontal position of the gradient pegs carefully plotted on the plan as shown, with dotted lines between them. The method here pursued, owing to the irregular formation of the ground, necessitated the route following a sinuous course.

The final line was then adjusted on the plan, following the position of the gradient pegs as near as possible, in giving the line a regular course with straight lines and easy curves, regard being paid, with a view to a moderate outlay of capital, to equalize as much as possible the cuttings and embankments. The alignment of this road, although following to a considerable extent a sinuous course, does not add in any appreciable degree to its length compared with a practically straight road along and down the side of the hill. A sinuous course is in most cases a decided advantage, from a maintenance point of view, as on a winding road the wheel traffic spreads over the whole surface, which seldom takes place on a straight road, especially when level horizontally.

The route was then staked out on the ground, and the final detailed or working section prepared, with numerous cross-sections taken at convenient points, to determine exactly where retaining walls were necessary to supplement the earthworks in forming the road. The longitudinal section in such cases should also have marked on it the level of the ground, the level of the proposed work, and the height of embankment or depth of cutting, at numerous points, where the level of the ground has been taken; these should be found by calculation and not by measurement from the plans.

The trial-section of this road showing the gradients is illustrated at fig. 12, Plate I., and the working-section of a portion of the road is shown at fig. 12A, Plate I. Detailed drawings of bridges, culverts, retaining walls, and the road covering should be provided, and a detailed written specification prepared showing the manner in which the embankments, excavations, masonry, and other works are to be executed.

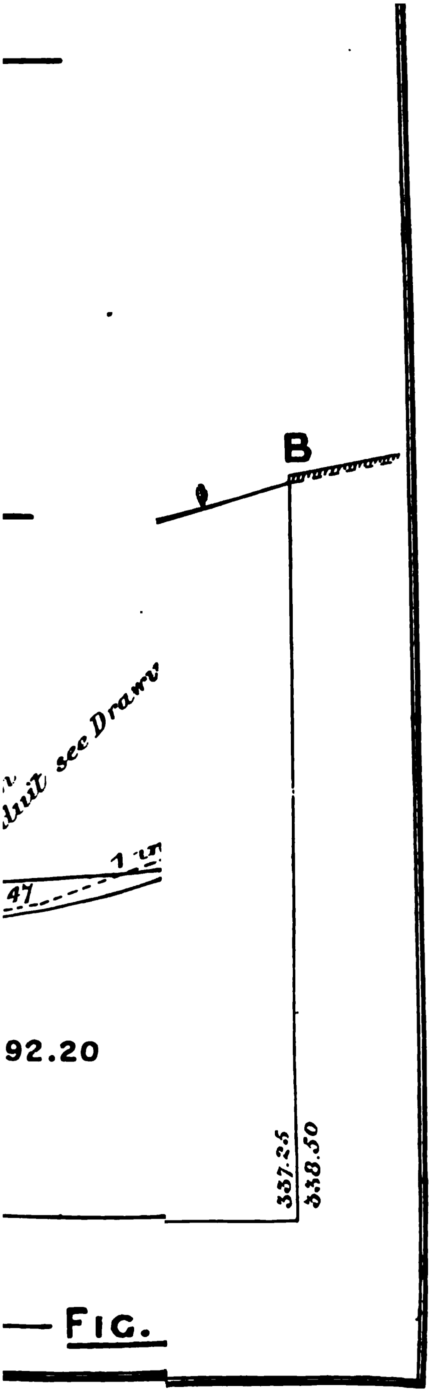
41. The principles laid down in this and the preceding chapter equally apply to carrying out improvements of gradients on existing roads which, in hilly districts in most parts of the country, have to a great extent been laid down with only one object in view, namely, that of a direct line. The great sacrifice thus entailed, through steep gradients, in the cost of transportation, is a serious one, which could have been avoided in many cases by a little scientific knowledge of what is necessary in laying out a new road, so as to accomplish the greatest amount of work in haulage at the least expenditure of motive power. In other words, a lasting benefit would

have resulted had these roads been properly laid out when constructed, in the form of greater facility for travelling, avoiding wasteful expenditure of power in the conveyance of goods, less wear of horses, and repairs to vehicles, as well as a saving of time. The surface is less damaged by the traffic on roads having easy gradients, and involves less expenditure for maintenance.

42. Improving Gradients on existing Roads.—The following example of a cross-country road is a case in point where had the route followed the proposed line, one horse could, without any great exertion, have hauled an ordinary load, which requires two horses to perform over the existing road at present.

On the plan, fig. 13, Plate II., the existing road, so far as where the steep gradients are situated, is shown at A B, which it will be observed is nearly straight from point to point. On referring to the longitudinal section of this road, fig. 14, Plate II., it will be seen that the gradients are very steep on either side of the first ridge with a valley and ridge beyond. This case, like many others situated in similar circumstances, may be taken as analogous to the road between London and Barnet already mentioned, and as an instance of laying out a road with useless ascents when a subsequent descent must be made. The number of feet actually ascended is most unnecessarily increased when such height once gained is lost again. The improvement referred to is shown on plan, at A, C, B, fig. 13, the length of deviated road compared with the present one being about 180 yards longer. This additional length to be traversed is of little consequence, however, when the improved gradients are taken into consideration. A longitudinal section of the proposed road is shown in fig. 14, Plate II., and also the surface of the existing road is represented on the section by dotted lines.

The proposed new road, after leaving the existing one at A, branches slightly towards the west on a rising gradient of 1 in 38, and attains the ridge of the first hill at C; as the surface of the ground falls considerably between that point and D, it is necessary to introduce a minimum gradient in order not to lose any height already gained. By this means the point D is reached, where, owing to the ground rising somewhat abruptly towards the north, it is necessary to curve the line towards the east, and crossing the existing road at E, is gradually curved backwards till it joins the present road at the point B. The gradients on the deviated line of road, it will be observed, are such that a horse, by a slight effort, could surmount the steepest incline readily, even with what is usually considered a load on a level road. In connection with this subject, it is necessary to bear in mind that a horse can, for a short time, exert an effort two or three times greater than that which he can keep up steadily during a day's work. Steeper ascents for short distances can therefore be surmounted, while excessively steep ones may be overcome oftentimes by the horses voluntarily pursuing a zigzag course in search of an easier gradient.



[*To face p.* 54.

43. The advantage of straightness is in many instances overestimated. The curving road round a hill may often be no longer than the straight one over it; for the latter is straight only with reference to the horizontal plane, but curved as to the vertical plane, while the former is curved as to the horizontal plane, but straight as to the vertical plane. This is strikingly illustrated by the road shown on Plate I., fig. 11. The distance between B and E, taken in a straight line over the rising and falling ground, is practically the same as on the curving road round the hill from the same points, namely, B and E.

44. The improving of many roads could be effected, in comparatively short stretches, by re-locating the roads, which would result in many advantages. A common defect in country roads, especially in undulating and hilly districts, is that distance has been saved by a disregard of the desirability of easy gradients. In the original location of many roads the errors already referred to exist in a more or less pronounced manner, and when from such causes as building operations the road cannot be improved. It is therefore a permanent legacy established for all time coming, to the disadvantage of those using the highways so affected. In improving sharp corners the shortest radius of curvature of from 50 to 100 feet may be employed, and that portion of the road situated on the curve should be practically level horizontally and super-elevated at the outer edge by continuing the camber from the inner water-table to the centre and beyond to the outer side of the road. This arrangement, although hitherto not much practised in this country, becomes necessary where motor car traffic exists in order to prevent side slipping and ensure safety when traversing the curved portion of the road.

The altering and improving of dangerous corners, the reducing of gradients, and the widening of narrow roads so necessary in many localities, have not, unfortunately, been hitherto carried out by County Councils in so expeditious a manner as was to be expected on the advent of fast travelling vehicles.

45. It is often stated that in most parts of the country roads are already located and constructed so that small improvements are only necessary to cope with the increasing traffic. This may be so far the case in regard to dangerous corners and steep gradients, but the congestion of traffic met with in most cities and many large towns clearly points to the immediate necessity of constructing new direct and wide main roads from these centres of activity into the adjoining counties. On the other hand, it is also necessary to form new roads passing on the outskirts of these towns for the exclusive use of fast through traffic from points situated on either side of these populous places. This arrangement would not only avoid the through traffic passing along the already busy local thoroughfares of these towns, but would provide a means of accommodating all descriptions of motor

and fast travelling vehicles. These new arteries would, it is considered, meet the exigencies of present-day traffic, which has increased greatly in amount and changed in character, and would appear to justify their construction.

46. Many proposals have been made of late for the constructing of new trunk roads from London to the different counties surrounding the city. One of the latest schemes is a proposal to construct a trunk road from London to Brighton exclusively for the use of motor car traffic. The length of this new road is forty miles, and the cost is estimated at £1,000,000.*

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* *Surveyor and Municipal and County Engineer*, 10th November 1905.

CHAPTER III.

EARTHWORKS, DRAINAGE, RETAINING WALLS, CULVERTS, BRIDGES, AND PROTECTION OF ROADS.

47. Equalizing Earthworks.—Earthwork, as generally understood, embraces not only the excavation of the looser materials of the earth's crust, but rock also. In selecting the final direction and gradients of a new road, it is obvious that due regard must be observed to equalizing the cuttings and embankments, so that the earth taken from the one may be sufficient to form the other, or, in other words, the earthwork should be redistributed along the line of road. Unnecessarily heavy works are thereby avoided, and the outlay of capital involved is a consideration of greater importance than the mere maintaining of a strictly direct line. In the generality of cases occurring in practice the engineer is obliged, in arriving at this, to resort to a system of approximation; for this purpose the line of road should be divided into several sections, to be treated separately in the first instance, and finally in connection with the adjoining sections.

It is advisable, in many instances, in carrying out the adjustment of the earthworks, owing to the distance apart of the cutting from the embankment on a line of road, to construct the embankment when possible from side-cutting, thus avoiding the great expense necessitated by having to transport the material an excessive distance. In like manner, transferring earth from a cutting situated a considerable distance from an embankment on the line of works, especially when of an unsatisfactory nature, may in some cases be deposited on the adjoining ground contiguous to the works. This method of disposing of the earth from the cuttings is known as forming a spoil-bank.

48. Transverse Balancing.—Transverse balancing in hilly parts, or in sidelong ground, as already indicated, is accomplished by locating the centre line of the road, so that the cutting from the one side will form the embankment on the other. The cost of transport compared with that of excavation and the value of land from which side-cutting is taken, or spoil-banks are formed, will determine the distance within which the balancing of the earthworks must be established.

49. Side Slopes.—The forming of the side slopes requires considerable attention, so as to ensure stability, and prevent slipping. The resistance to slip arises partly from the friction between the grains composing the soil and partly from their mutual adhesion.

Friction is, however, the only force which can be relied upon for permanent stability, as the adhesion of the earth is destroyed by the action of air and moisture, this being especially the case during alternate frost and thaw. The nature of the soil, its condition as to internal moisture and the atmospheric influence, therefore, combine in fixing the inclination of the side slopes.

50. The slopes of earthwork are generally described in the ratio of the horizontal breadth to the vertical height. The angle of repose, or, as it is generally termed, the natural slope at which different kinds of earth, by friction alone, will remain permanently stable, is shown in the following table given by Professor Rankine in his work on *Civil Engineering.*

TABLE VIII.

Natural Slopes of Earths (with horizontal line).

Earth.	Angle of Repose.	Coefficient of Friction.	Customary designation of Natural Slope.
Dry sand, clay, and mixed earth, ...	from 37°	0·75	1·33 to 1
	to 21°	0·38	2·63 to 1
Damp clay, . . .	45°	1·00	1 to 1
Wet clay, . . .	from 17°	0·31	3·23 to 1
	to 14°	0·25	4 to 1
Shingle and gravel, . .	from 48°	1·11	0·9 to 1
	to 35°	0·70	1·43 to 1
Peat, ...	from 45°	1·00	1 to 1
	to 14°	0·25	4 to 1

The slopes most frequently adopted for earthwork are those designated 1½ horizontal to 1 perpendicular, and 2 to 1, corresponding to the angles of repose, 33½° and 26½° nearly.

51. Rock cuttings, the material of which does not disintegrate on exposure to the action of the weather, may be formed with perpendicular sides, but generally a slope of 1 horizontal to 2 perpendicular is given to admit of free action of the sun's rays on the road surface.

52. For a similar reason the side slopes on the south side of roads in northern latitudes are sometimes made flatter than the natural slope given to that part of the cutting on the north or opposite side. By this arrangement the surface of the roadway is exposed to the action of sun and air, causing rapid evaporation of the moisture on the surface.

53. Stratified soils and rocks, which have a dip to the horizon, are liable to slips caused by one stratum becoming detached by the action of frost or water and sliding on another, the worst combination being that of soils formed of alternating beds of clay and sand.

54. Embankments.—Embankments of any height should be formed with great care. They may be carried out by laying the material from the excavation in successive layers of from 3 to 4 feet in thickness, and thoroughly pounding each layer. This is, however, an expensive process, and seldom resorted to in ordinary works of any extent.

The method usually followed is to run the extreme outsides of the embankment first, and then gradually fill up the centre portion, by which means greater solidity is secured than when the embankment is carried forward and the material tipped from one end only. By this arrangement the layers are formed with an inclination inwards, counteracting, so to speak, as a whole, any tendency to slip outwards. During the construction of an embankment, due consideration must be given to the settlement of the loose or excavated material which takes place. It is advisable to make the height and width of the embankment greater than the dimensions ultimately required; the amount allowed for settlement varies according to the class of material, but may be from one-twelfth to one-fifth of the total height.

It is usual, as a precautionary measure, to form a slight excavation at the tail or toe of the slope to give the material forming the embankment additional stability.

55. Consolidating Embankments.—The compacting of embankments and road beds generally, until the material composing them forms a uniform and unyielding surface, is carried out in the United States and other countries by the use of a horse roller weighing about 3 tons. The roller is about 5 feet wide, and is ribbed or corrugated similar to corduroy. The formation level or foundation of a road is consolidated in this country by the aid of a steam roller. It requires, owing to its weight, very careful handling on newly-formed embankments of any great height. Depressions are made good by the application of material similar to that of which the formation of the road is composed.

56. Embankments on Sidelong Ground.—On sidelong ground different methods are employed in order to secure a solid basis for an embankment sustaining a road. Where the inclination of the natural surface of the ground is not great, and the formation of the road is partly in cutting and partly in embankment, the method of cutting the surface of the ground into steps, shown in fig. 15, is generally adopted. The natural surface of the ground is represented by *a b*, the steps or benches are shown at *f*, *f*, *f*, and the formation level at *c d*. The best position for these steps is perpendicular to the axis of greatest pressure.

On sloping ground under similar conditions, but with the natural surface lying at a considerable inclination, the above method of construction will not be sufficiently secure, and recourse must be had to some other means of effecting this.

57. Retaining walls of sufficient thickness, built either dry or with the stones laid in mortar to support the roadway, are constructed for this purpose. These walls may have to be built on either side of the roadway to sustain the embankment on the lower side, and the portion in excavation on the higher part. The wall which sustains the embankment should be built up to the level of the roadway and a parapet or fence wall erected upon it, to protect pedestrian and vehicular traffic against accident. When necessary to erect a wall to form the slope or sustain the ground in excavation, it should be carried up to a height to meet the natural surface of the ground. The arrangement of retaining walls on sidelong cutting is shown at fig. 16, *a b* being the natural surface of the ground. Considering the inclination of the natural surface of the ground *a b*, it is evident that such a long embankment slope as *d b* would endanger the stability of the roadway. It is necessary, therefore, to secure the solidity of the road in a more permanent manner by the substitution of retaining walls for an embankment on such a slope as that represented in the diagram. Under certain circumstances it might also be advantageous to build a retaining wall at *c*, to retain the part in excavation, as a long slope exposed to the drainage of the higher ground would in time cause the material composing it to be washed on to the road, and in all probability create a landslip. If a footpath is to be formed alongside of a road in sidelong ground it should be placed on the portion embanked, leaving as much as possible of the solid ground for vehicular traffic.

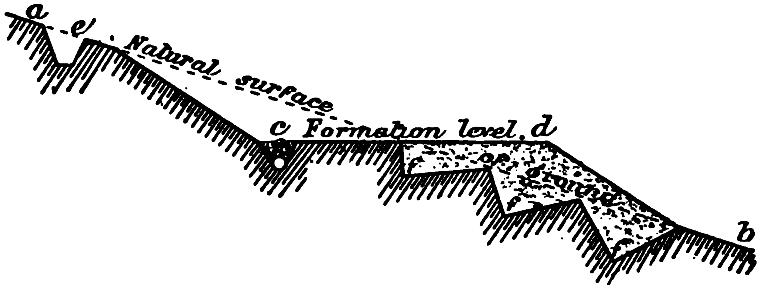


FIG. 15.—Cross-section of a road showing method of stepping adopted in sidelong ground.

58. Roads formed over Low-lying or Marshy Ground.—In crossing plains or marshy ground it is necessary to form the surface of the road well above the general level of the surrounding country in order that it may be kept as dry as possible. This is particularly the case where the line of communication traverses a district subject to inundation. The best method of accomplishing this is to excavate side trenches at sufficient distances apart on either side of the roadway, from 3 to 4 feet deep, 18 inches to 2 feet wide at bottom, and having side slopes 3 to 1. This excavated material is made use of in raising an embankment between the trenches, so as to elevate the road surface above any possible inundation, and the side ditches will serve to collect the surface water and discharge it to the nearest stream or water-course.

Soft or marshy ground is a difficult as well as an expensive obstacle to overcome in the construction of a new road. It must be borne in mind that laying out a road under these conditions is only undertaken when no other reasonable alternative is possible, such as deviating from a direct line by making a detour even of considerable length. The work can only be accomplished properly by draining the subsoil, so as to consolidate the ground as much as possible, and forming an embankment to carry the roadway. This is effected by excavating a trench in the soft ground to a depth varying with the degree of difficulty to be overcome, and then filling in the trench with stable material. The level part of the excavated portion of the trench is made of a width corresponding to the width of the formation level of the road, while the slopes of the trench should be inclined at the angle of repose of the soft material composing the natural ground. The slope of the stable materials forming the embankment is made to correspond with that of the trench slopes, and as this is much flatter than necessary, a broader foundation and consequently increased stability are secured.

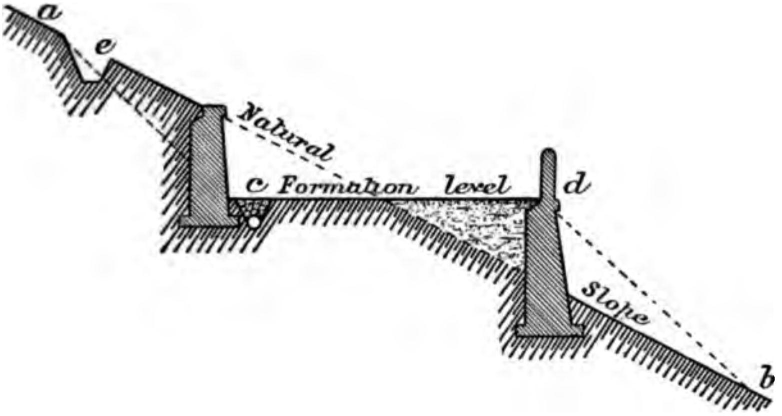


FIG. 16.—Cross-section of a road showing arrangement of retaining walls in sidelong ground.

Another method of making soft ground suitable for carrying a roadway is to drive in short piles; this has the effect of consolidating the mass of soft earth. Fascines, hurdles, and dry peat have also been at times employed for a similar purpose with good effect. Should these expedients fail, a bog or marshy ground may be made secure by tipping sand, gravel, or stones upon it in order to form an embankment which will rest on the hard stratum below the moss, and raising the upper surface to the required level. The slopes of an embankment thus formed assume the same inclination as they would have under ordinary conditions.

59. Half-widths and Extent of Ground required.—When the inclination of the slopes has been determined, the half-widths, or distance on either side of the roadway, may be staked off, and the area of land computed, allowing 6 feet on either side beyond the formation level or the edge of the slope.

60. Finishing Slopes, Drainage.—The slopes of cuttings and embankments should be dressed to regular surfaces with soil from 3 to 6 inches deep and sown with grass seed. The vegetation to a great extent diminishes the effect of rain washing or running down the slopes, forming gullies, and helps to prevent any tendency to side-slips. Where the slopes are exposed at times to the action of running water they should be covered with dry stone pitching 12 inches thick and of a height sufficient to protect the material of which the embankment is formed.

61. The numerous and diverse nature of circumstances met with in the laying out and construction of roads are such that no definite rules can be laid down to embrace all cases. The engineer will have to consider which form of construction will best suit the particular piece of work undertaken, with a view to economy in carrying out the operations involved, the stability of the works generally, and the subsequent maintenance of the road. In executing the necessary work in cuttings and embankments, level pegs are fixed indicating the depth or height of formation at convenient points, so that the workmen are enabled, by the use of boning rods or cross heads, to keep the intermediate position of the earthwork at its proper level. Important points, such as where a curve joins a straight line, should be transferred during the progress of the works by means of pilot pegs. This is accomplished by ranging a straight line from the point in question, fixing two pegs clear of the line of works and measuring the distance apart of these; the tangent point can then be readily re-established after the earthwork is completed. A similar operation should be carried out where important structures are to be erected.

The volume or cubical quantity of a piece of earthwork is ascertained by computing the area of a series of cross-sections of known distances apart, and the quantities obtained are stated in cubic yards.

62. Drainage.—The drainage of roads is of two kinds, namely, surface and subsoil. It is one of the most important operations in connection with the construction of a road, as on its efficiency the subsequent maintenance of the surface will greatly depend. The slopes in cuttings on sidelong ground are generally the most troublesome, and great pains should be taken in order to thoroughly intercept, from the rising ground, any flow or filtering of water towards the road bed. This is readily accomplished by forming catch-water ditches or drains on the uphill side of the cutting a few feet back from the crest of the slope or point where the excavation joins the natural surface of the ground, as at *e*, figs. 15 and 16. These, if possible, should be carried to the most convenient water-courses; but where the surface of the ground is such that a sufficient fall cannot be obtained unless at great expense in cutting and laying drain pipes, the water may be conveyed down the slope to the side channel or covered drain near the formation level as at *c*, fig. 15. When open conduits are formed for this purpose, the slope should be protected by forming a rough pavement, as the soil cannot withstand the action of the water on the steep slope generally given to cuttings. This object, however, is better attained by laying stoneware drain pipes in the slope 18 inches below the surface. The slopes of cuttings may, when necessary, be further protected by laying drains in a trench 18 inches deep, cut in an oblique direction up the slope, filling the space up to the surface with stones, and connecting them to the drains at the bottom of the cutting. Where springs occur, the water should be carried away by laying the pipes to the side drains, or by some other effective means.

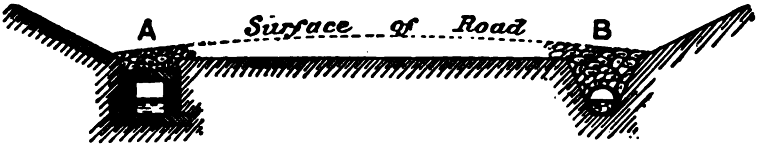


FIG. 17.—Cross-section showing side drains at formation level of road.

Drains should also be constructed at the foot of a slope in cuttings, varying in depth from 18 inches to 3 feet, according to circumstances. These may be built with either brick or stone; a less expensive method, however, and much more effective and durable, is made by laying salt-glazed plain pipes in the trench and filling the space up to the surface with broken stones, which must be free from dirt, to a height of 6 inches above the formation level of the road. Fig. 17 shows the two methods of construction, that at A being built of stone, while the drain at B is formed of salt-glazed pipes, the space above, in either case, being filled in with small stones.

63. The lower half of drain pipes may be surrounded with clay to prevent any water lying around them. This precaution should be adopted when the drain has but a small inclination, as the water in the pipe will be discharged more quickly and prevent the lower portion of the ground becoming waterlogged.

64. In sidelong ground, and on level tracts of country, the side ditches should be formed before the cuttings are excavated and the embankments formed, as greater stability will be ensured by the ground being in a dry state.

65. The drainage of embankments does not require such extensive operations as those necessary in cuttings. The water from the surface of the road should be carried by the water tables or side channels to suitable points where it can be conveyed down the slopes in open troughs. It is usual to form an open ditch on either side, nearly parallel to the axis of the road and at the tail of the embankment, to collect and convey the surface water from the road and slopes of the embankment to the nearest water-course or point of discharge. Where a falling gradient in a cutting adjoins an embankment, a similar course is pursued when such cannot be diverted, great care being exercised to have the conduit of sufficient capacity to convey all the water which will collect in the cutting under the most unfavourable circumstances. On sidelong ground it is seldom necessary to make an opening at the toe of an embankment, the natural slope of the ground being in most cases sufficient to carry away the limited amount of water likely to collect there. All drains and open ditches should have sufficient capacity and acclivity to receive and convey away quickly all the water that may find its way into them; this will also be influenced by the nature of the soil in which they are placed. When a footpath exists at one or both sides of a road, the surface drainage collecting in the side channels is conveyed by pipes laid under them to the ditches, or drains, or on to the surface of the ground on the field side of the footpath.

66. Subsoil Drainage.—The drainage of the subsoil provides for the removal of any water found in the soil immediately under the road covering in cuttings and on level tracts of country. This is an essential and important requirement in road construction, and on the efficient state of repair in which the subsoil drainage is maintained, will the cost of keeping the surface of a road in good repair depend.

The materials composing a road covering placed on a naturally wet, retentive, or undrained soil, such as clay and kindred earths, will go quickly to pieces by the traffic passing over it or by the action of thaw succeeding frost. The combined effect of these influences, converting the whole coating material into a disintegrated mass, is simply ruinous.

On soils of a siliceous and calcareous nature, and rocks generally, there is no great difficulty, as their porous nature assists in securing a dry and solid foundation.

67. The side drains in cuttings, and the open ditches on the level portions of a road, will, as a rule, be sufficient for this purpose, even where the roadway is of a great width.

It is the argillaceous and allied soils which require careful treatment, as, being of a retentive nature, they become very unstable when in contact with water and the action of frost. The drainage of such soils may be effected by forming transverse or cross drains in the form of the letter V, as shown at *b*, *a*, *b*, fig. 18.

These drains should consist of salt-glazed plain pipes 2 to 3 inches in diameter, laid about 15 to 18 inches below the formation level at centre, and properly connected to the side drains. The junction is preferably made at the highest point of the pipe in the side drain, and an opening formed of dry stone built, over where they join, up to formation level foı inspection from time to time. Ordinary field or agricultural drain pipes are sometimes used, but being porous are liable to injury by frost, and cause great inconvenience and damage by breaking, as well as a temporary derangement of the drainage of the subsoil, which is sometimes difficult to locate. The trenches should be filled up with clean gravel or small stones, free from all clay or other soft matter, care being taken to hand-pack the material round the joints of the pipes.

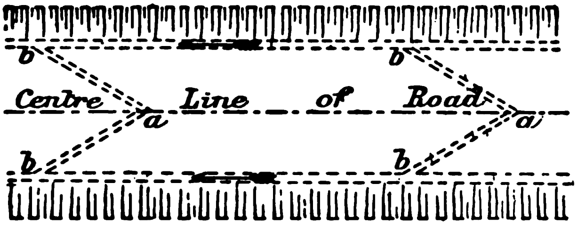


FIG. 18.—Diagram showing arrangement of subsoil drains in retentive soils.

The diagram at fig. 19 shows a cross-section of a road with the mitre drains at *a*, and joining the side drains at *b*, and a cross-section of the mitre or transverse drain is shown at fig. 20. It is not essential that these cross drains should have a great fall; the purpose may be properly served by giving them an inclination of 1 in 50. The nature of the soil will afford the means of determining at what distance apart these cross or mitre drains should be placed; this may vary from 15 feet in very wet situations, increasing in distance to 30 or even to 50 feet where the subsoil is of a drier and less retentive nature. The surface water from the roadway is collected in the side channels and conveyed, where the level of the roadway is at or near the natural surface of the ground, to the ditches, by outlets cut at certain intervals on either side of the roadway. Where footpaths exist alongside of a road, drain pipes are laid across and underneath the footpath at convenient points, the outer edge of

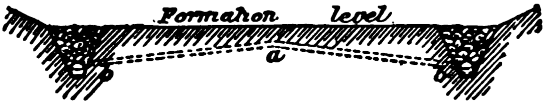


FIG. 19.—Cross-section of road showing mitre drains.

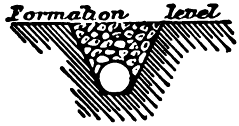


FIG. 20.—Cross-section of mitre drain.

these pipes at the roadside being protected from damage by passing vehicles, by fixing a stone at each side of the drain pipe well into the ground, and covering them with a flat stone projecting 2 inches beyond the conduit, but in line with the edge of the footpath.

68. On embankments, especially in sidelong ground, the surface water, as already mentioned, is conveyed to the open ditches in wooden troughs, creosoted, or tarred and sanded, and fixed in the slopes. This method, although satisfactory in many cases, is not to be recommended as a permanent arrangement; a drain constructed of salt-glazed faucet and spigot pipes laid in clay puddle, or covered with concrete and finished at the toe of the slope with masonry, is required to keep it in position.

It is necessary to exercise great care in carrying out the work by placing puddle around, or otherwise protecting the joints, so as to ensure that no water will be permitted to percolate through the earthwork, which, if allowed, would in all probability result in considerable damage being done to the embankments.

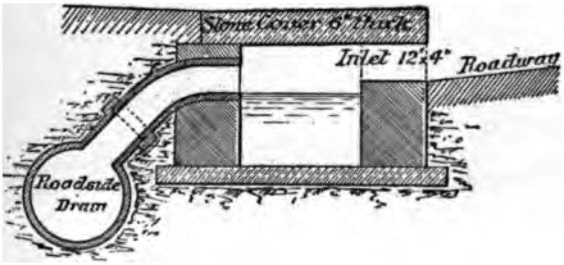


FIG. 21.—Diagram showing sand trap.

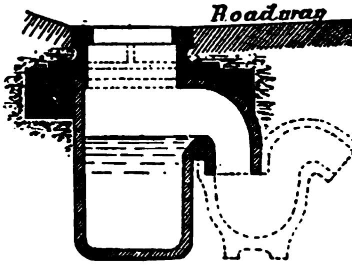


FIG. 22.—Diagram showing sand trap.

69. Drains in Cuttings and Different Arrangements of Sand Traps or Gullies.—In cuttings, the system followed is somewhat different, being generally effected in the following manner. The side drains are utilized as a means for the disposal of the surface water which, in the first instance, enters a gully or sand trap, the overflow from the latter being connected to the side drain. The use of a sand trap, especially on a road having a considerable fall longitudinally, is to intercept any heavy matter or detritus which would otherwise gain entrance to the drain, and in course of time, by repeated accumulations, cause the drain to become choked. The simplest and cheapest form of sand trap is represented at fig. 21, built of brickwork with suitable covers, and at fig. 22, which is made either of earthenware or cast iron. Stoneware gullies are, as a rule, liable to damage by the passing traffic, and should be placed in the least exposed situations, or clear of the water channels. This form of trap is also made in detached portions, the basin or stoneware part forming the trap, with a cast iron cover and grating fixed on the top. It is claimed that this form of gully trap is unbreakable under the heaviest class of traffic. Sand or gully traps are also made of cast iron in one piece and in different sizes to suit different localities. The gratings are detachable, and, on the whole, this class of trap is the best possible to adopt, and serves most effectively the purpose intended. This class of gully or sand trap is shown in fig. 23.

When one road crosses another, it often happens that two or more drains have to be connected to one gully or sand trap. This is most conveniently accomplished by building it of stone or brickwork, with a pavement or concrete floor of a sufficient area to embrace the side walls and form a foundation. The floor should be at least 18 inches below the level of the outlet pipe, to collect the detritus or heavy matter. If the trap be built of brick the walls need not exceed 9 inches in thickness, unless the drain is exceptionally deep, when it will be advisable to increase the thickness of the walls. A convenient size of trap for such a situation, with three inlet pipes, is shown in fig. 24.

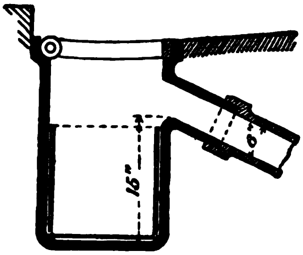


FIG. 23.—Cast iron sand trap or gully.

The brickwork is brought up to within a few inches of the level of the water table, the covering and grating being either of cast iron fitted properly into the brickwork, or it may be finished with a stone cover, and a wrought iron hinged grating dished out to admit of the water from the channels passing freely into the sand trap. A space nearly equal in size to the iron grating requires to be cut out in the centre of the stone cover, provision being made for properly fixing the grating to it by means of batts.

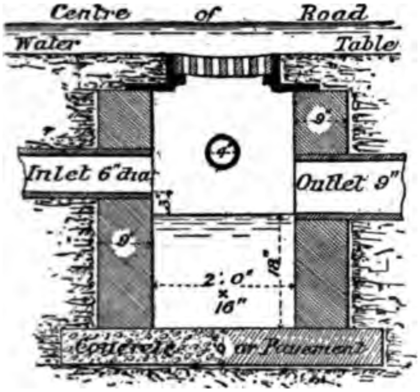


FIG. 24.—Sand trap with three inlets.

These sand traps should be cleaned out periodically, and also immediately after a heavy fall of rain, so that the road detritus and sand may be prevented from entering the outlet pipe. The inlet pipe or pipes should be placed at a higher level than the outlet pipe, to ensure a rapid discharge; 2 to 3 inches being quite sufficient for this purpose.

70. When it is necessary to lay a drain under a road, the work should be of a substantial nature, so as to avoid any possible derangement of the drainage, and probable damage to those using the road, by its failure.

Drains for conveying water under a road should be built of good stone and bedded in cement, with paved floor and substantial covers. Salt-glazed or earthenware spigot and faucet pipes are also employed; these should be cement-jointed, and if necessary protected with a layer of concrete under and round the outside of pipe.

71. **Retaining Walls.**—Retaining walls are structures in masonry, laid dry or in mortar, designed in various forms to support the sides of roads on hillsides, or when land is not available for forming side slopes beyond the formation level of the road. Where building materials of sufficient size can be procured, the retaining walls may be built of stones laid dry; when, however, the materials for this purpose are not large, flat-bedded stones, it is advisable to use mortar in building the walls.

With suitable material, drystone retaining walls are well adapted for road work, on account of their self-draining properties and their cheapness. The outside face is generally built with a batter, either straight or curved, varying from 1 in 8 inches to 1 in 12 inches; any excess of batter greater than 1 in 6 should be avoided where mortar is used, as the action of the rain tends to destroy the joints by washing it out, and affords lodgment for seeds of vegetation, the roots of which penetrate the wall and injuriously affect the adhesion between the mortar and stone. Retaining walls built with stones and mortar are rendered more secure from the effects of water by having drystone packing, usually 12 inches thick, set by hand at the back of and between the wall and earthwork. Weeping holes, formed of 2- or 3-inch pipes, should be built into the wall at different levels; but especially at the base of the wall, and at a distance of from two to four yards apart, according to the nature of the soil and the dip of the strata.

The top of the retaining walls should be properly finished and protected by a coping of stone, close jointed, to prevent rain finding its way into the body of the wall.

Drystone retaining walls are generally finished on the top with a sod coping laid in two rows; when properly carried out, this method of protecting the walls suits the purpose exceedingly well. The profile or cross-section, and the thickness to which retaining walls are built, vary according to their position relative to the adjoining work and the nature of the material to be retained.

The foundations of retaining walls are subject to considerable and unequally-distributed pressures. They should be of a width or area sufficient to bear safely the pressure which they have to sustain according to the nature of the ground on which they are placed. A suitable drain should be laid at the base in front of a retaining wall to collect and convey any water escaping from behind the wall. Ordinary foundations may be classed under the following heads: (1) On material, the stability of which is not impaired by saturation with water, such as rock; (2) on firm earth, sand, gravel, and hard clay; and (3) on soft earth. The area of the foundations may be increased to any desired extent by forming steps beyond the thickness of the wall proper, so that the weight of the structure may be distributed over a large surface. Rock of a moderately hard description will bear safely 9 tons per square foot; firm earth 1 ton to 1½ tons; soft earth, on the other hand, is only capable of bearing a very limited load; and to ensure safety the ground should be well drained, the soft earth removed by cutting a trench and substituting stable material, such as sand or concrete. In extreme cases it is necessary to drive short piles into the ground to compress and consolidate the soil, on which a platform is fixed, the heads of the piles being surrounded with concrete. The depth to which a foundation should be excavated must be such that it will be below the disintegrating influence of frost: 2 to 4 feet is considered a safe depth in Britain, while in countries subject to severe and long-continued frost a depth of from 4 to 6 feet is necessary.

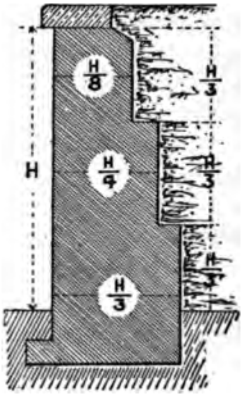


FIG. 25.—Section of retaining wall.

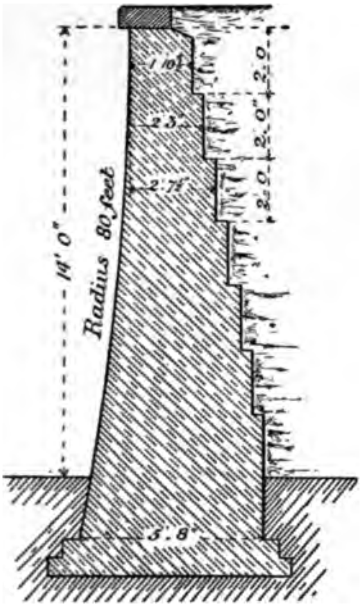


FIG 26.—Section of retaining wall (built of brickwork).

72. Dimensions of Retaining Walls.—In determining the proportions to be given to retaining walls, the engineer is guided by the experiments, and from the successful results attained in existing structures which have withstood for a considerable period of time all the usual causes of destructibility. From these examples many practical rules have been deduced for the design of stable and economical retaining walls, as well as for the thickness of abutments and arches of bridges and culverts.

For retaining walls 6 to 10 feet high a thickness of one-fourth of the height of the wall above the natural ground is generally allowed. In large structures built of masonry, the height of the wall above the ground level is divided into offsets, and the thickness is varied from one-third to one-eighth of the total height, as shown in fig. 25.

The following dimensions are extensively used in building retaining walls with brick, viz., the thickness at the top of the wall is made 1 foot 10½ inches, and at every fifth course downwards the thickness is increased by half a brick, the face of the wall being built with a batter of 1 in 6 to 1 in 8, which is generally curved as shown at fig. 26. In retaining walls constructed of stone without mortar, the thickness may vary from one-third to one-half the height, the face being built perpendicular or with but a slight batter, to avoid as much as possible rain-water being carried inwards to the earth backing, which would occur if the joints were inclined by giving the face an excessive batter. Should it be found necessary to batter the face of a wall built dry, the difficulty alluded to may be obviated by pointing the outside joints of the wall. Trautwine's rule for a retaining wall, which sustains a backing of sand, gravel, or earth, level with its top, is, that the thickness of the wall should be not less than that stated in the following table, when the foundations are about 3 feet deep, the backing being deposited loosely, as when tipped from carts, wagons, etc., and the batter not exceeding 1½ inches to a foot.

Table IX.

Wall of cut stone or first class large-ranged rubble in mortar, ...	·35	of its entire vertical height.	
Wall of good common scabbled mortar rubble or brick,	·4	do.	do.
Wall of well-scabbled dry rubble, ...	·5	do.	do.

The effect of stepping the back of a wall increases the friction of the earth against it, giving increased stability, so that when the thickness has been proportioned with a vertical back by Trautwine's rule, it may be converted into one having onsets, which has the advantage of greater resistance to overturning, and yet contains no more material. The method of arriving at this is as follows :—From the point *c*, fig. 27, half the height of *a b*, draw a line from *d* one-half of the thickness of the wall at the top *a a*, through *c* to *e*, and from the latter draw the vertical line *e f*; divide *d f* into any number of equal parts, for instance three, and produce vertical lines to the base *b e*; then divide *f e* into one more equal part than *f d* contains, and draw horizontal lines crossing the vertical ones. From the points of division draw the line forming the offsets as shown in the figure.

73. Surcharged Retaining Walls.—When a retaining wall is surcharged, that is, retains a bank which slopes backward to a higher level than the top of the wall, the thickness, according to the foregoing rules, must be increased.

This class of wall, fig. 28, is principally made use of in cuttings, but in some cases walls of this description are built to retain the toe of an embankment. The following table, given by Molesworth, shows how the thickness of a surcharged wall of rectangular shape may be arrived at.

The height Y is substituted for H, in fig. 25, or height of the wall from ground level, and is the perpendicular at the end of a line L equal to H, measured along the slope to be retained. The value of Y for various slopes is as follows:—

TABLE.

Y = 1·71 H. in slopes 1 to 1
„ = 1·55 H. „ 1½ to 1
„ = 1·45 H. „ 2 to 1
„ = 1·3 H. „ 3 to 1
„ = 1·24 H. „ 4 to 1

74. Counterforts.—Counterforts are projections of masonry at the back of a wall, built at intervals, and of a rectangular shape; they are introduced to increase by their weight the stability of retaining walls, but this depends on the efficient manner in which these are bonded to the retaining wall at their junction.

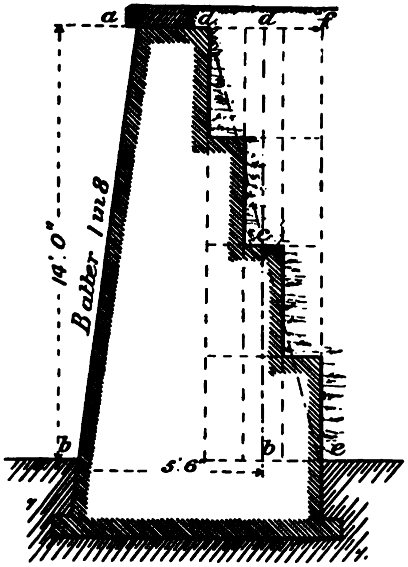


FIG. 27.—Section of retaining wall, proportioned by Trautwine's rule.

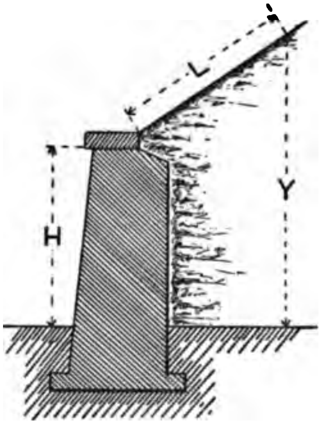


FIG. 28.—Section of surcharged wall.

75. The result of the experience of Sir B. Baker in connection with the building of retaining walls may be given. "In ground of an average character the thickness of retaining walls should be one-third of the height from the top of the footings. A wall quarter of the height in thickness and battering 1 to 2 inches per foot on the face possesses sufficient stability when the backing and foundations are both favourable." He also states that "under no ordinary conditions of surcharge or heavy backing is it necessary

to make a retaining wall on a solid foundation more than double the above or half of the height in thickness."

76. Breast Walls.—Breast or revetment walls are very useful in cuttings. They are generally employed to act as a covering for earth which has sufficient stability to stand vertically alone. They need not be of great thickness, provided they are of sufficient strength to resist their own weight; it is advisable to raise them above the level of the ground where the slope joins the wall, in order to prevent stones and earth, which may become detached by the action of the weather, from falling on the roadway.

77. Culverts.—Culverts are necessary to carry a roadway over a watercourse, and for conveying the surface water from the road, as also that from the drains in cuttings and open ditches running parallel to the axis of the road, which are conveyed and discharged into the stream.

Care should be exercised in determining the waterway necessary for culverts under varying conditions, so that the opening may be built slightly in excess of the actual requirements. If a culvert is built too small, it is liable, during floods, to be washed away, along with possibly a considerable portion of the embankment, causing interruption of traffic and heavy cost for repairs.

Culverts of unnecessarily large dimensions involve a needless increase in the cost of construction. The area of waterway required depends principally on the following considerations:—

The maximum rainfall during a severe storm.

The nature and condition of the soil, and the character and inclination of the surface.

The area to be drained, with special regard to the number and position of the branch streams which join that under consideration.

The annual recorded rainfall for any particular district does not aid the engineer to any extent. An average fall for a given period does not necessarily mean that a fixed quantity has fallen each day; it is possible that the total recorded amount in a certain time may have fallen on one particular day, and probably only during a few hours of that day. A thaw and heavy rain succeeding a fall of snow when the ground is frozen, and a heavy rainfall during a thunderstorm, are certainly the worst possible conditions to be provided for in practice.

The hard nature of the surface of the ground under the former conditions precludes any moisture being absorbed by the soil, and this circumstance, combined with the falling rain and melting snow, increase the difficulty of calculating the area of waterway necessary in any particular case. Data of a more or less valuable nature may be obtained by observing the flood-mark of a stream where it is confined within its banks; and by taking a cross-section of the stream the actual area may be computed, from which it is possible to determine with a reasonable degree of accuracy the necessary area of waterway. Should any other culvert be built over the same stream within a reasonable distance of the proposed crossing, the area of the existing opening should be measured, which will guide the engineer, to a certain extent, in determining what waterway will be necessary. The evidence also of local parties when available may likewise be of great assistance.

78. Materials used in Building Culverts.—Culverts may be constructed of stone, brick, concrete, iron pipes, trough decking on stone or brick abutments, or of salt-glazed or earthenware pipes. The simplest form in which a conduit built of stone can be made is shown in fig. 29. When suitable material is plentiful, this form of conduit is extensively employed. This is, however, an expensive method of construction, when high embankments are formed over the conduit, as, owing to the great weight, large covers of considerable strength are necessary, varying in thickness up to 12 inches. The side walls also require to be built of dressed stone, as the water flowing in the conduit would eventually find its way through the joints, if inferior masonry was used, and possibly wash away the earth backing by being thus softened. This may result in the failure of the structure and consequent stoppage of the traffic, as well as cause accidents, involving the authorities in considerable expense. When of a small size, and therefore difficult to get at, repairs cannot be carried out without stripping the material off the road. Experience of the maintenance of roads clearly indicates that conduits built of ordinary rubble, and with covers of insufficient strength, combined with the inferior quality of the stones often employed, cause great trouble and expense for repairs.

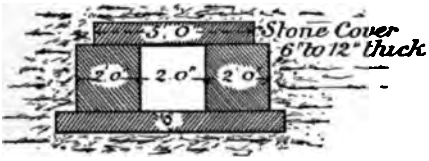
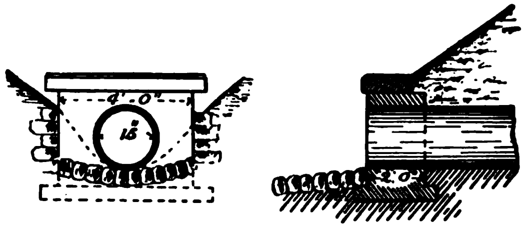


FIG. 29.—Section of conduit built with stone.

79. Salt-glazed or stoneware pipes are now generally made use of for conveying small streams under a road, and are a reliable substitute for the class of conduit just described, providing they are properly laid and jointed and the sides and top of the trench are filled in with suitable material. These drain pipes vary in size up to 24 inches in diameter. They can be laid in position quickly, and are comparatively less expensive than masonry conduits of a similar capacity. Two or more lines of stoneware pipes may be laid alongside of each other when the capacity of one is insufficient. The inlet and outlet ends of the smaller-sized pipes should be protected at the toe of the embankment by building round the outside of pipe flat-bedded stones finished with a sod cope on top. The large-sized class of stoneware pipes are generally protected by forming a pitched slope or wing-wall to retain the embankment in position, and likewise to assist in directing the current of water into the culvert on the up-stream side of the road.

In laying these pipes care should be taken to ensure a straight line being preserved, and that the outside joints are properly filled and finished with cement; the inside joints also should be pointed when possible, and thoroughly wiped to remove any projecting particles of cement, and so lessen the chance of obstruction. The trench should be filled up under and round the body of the pipes with material free from stones, such as sand, furnace ashes, or similar material, the whole being well punned. When stoneware pipes are situated under a high embankment, it is necessary to strengthen them by placing concrete under and around the outside of the pipes. The upper portion of the pipes should, as a rule, never be less than 2 feet below the surface of the road. Instances occur, however, where the conduit pipe has to be laid only one foot below the road surface in order to gain a sufficient fall, and in such cases the pipes must be bedded in and covered with fine concrete. This method should be avoided, if at all possible; but if it cannot be so, the expedient of raising the road level should be adopted, which is an expensive alternative. The outlet or tail-end of conduits should have a sufficient fall, so as to discharge the water quickly, and prevent backwater reaching the pipes. The freezing of water in the pipes, when such a condition exists, tends to destroy them, so that a proper inclination for both the pipes and the outlet of the stream is imperative.



Elevation. Section.

FIGS. 30, 31.—15-inch stoneware pipe drain or conduit.

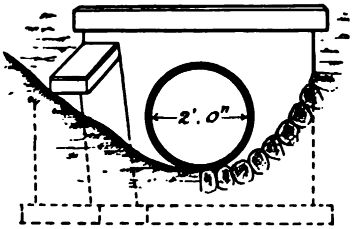


FIG. 32.—End elevation of 2 feet single stoneware conduit.

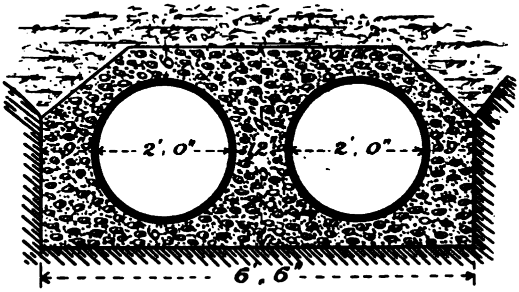


FIG. 33.—Section of double stoneware pipe conduit.

80. The diagrams, figs. 30, 31, 32, and 33, show the methods of construction adopted with stoneware pipes described in the preceding paragraphs.

81. Iron pipes are, under certain conditions, a very useful substitute for stoneware pipes and conduits built of stone or brick.

When the foundation is in soft material, a bed of concrete is formed, varying in thickness from 9 inches to 3 feet, according to the size of pipes and the solidity necessary to ensure stability. The joints when of spigot and faucet should be caulked; those having flanges should be bolted together, and any open spaces filled in with cement. The filling or backing should be carefully rammed to prevent the water forming a channel along the outside; the ends should also be protected by wing-walls or pitched slopes similar to the practice adopted in the case of stoneware pipes. The space between the wing-walls at either end should be pitched where any scouring action of the stream when in flood is anticipated, as by so doing the possibility of the foundations of the wing-walls being undermined is prevented, especially at the inlet end.

82. Arched Culverts.—It is more economical to build stone- or brick-arched culverts when the waterway of a stream necessitates a span of over 5 feet. The arch may take the form of a semicircle segment of a curved ellipse, or compound curve having different radii. The latter two forms are seldom employed in culverts of small span, that of the segmental arch being generally made use of. By adopting a flat arch, the embankment forming the approach to and over the stream may be reduced in height below what would be required if a semicircular arch were constructed.

The small convexity or rise of arch in relation to the span adopted at times in practice presents a weakness, while the horizontal thrust on the abutments, inseparable from this form of arch, is very great.

83. The semicircle should always be adopted in small spans, and, whenever possible, in those of moderate span, as this class of arch offers advantages in simplicity of form, great strength, and small lateral thrust.

84. The employment of steel trough decking for culverts has of late years been greatly advocated and applied in practice; they present a form of great strength, and can be erected expeditiously. The necessity for making an embankment in the case of arches is to a great extent, if not entirely, avoided by adopting this method of construction. Steel trough decking of a light section suitable for small spans, such as that adopted in the building of culverts, is manufactured for spans of from 4 to 10 feet, the weight of which is from 20 lbs. per square foot upwards.

85. The depth or thickness of arch stones for culverts depends upon the span, the form of the arch, and the class and quality of material employed in its construction. These remarks also apply in a measure to the thickness to be given to abutments, which will be treated under *Bridges.*

86. Figs. 34, 35, and 36 show the different forms of construction usually adopted and described in the preceding paragraphs. Fig. 34 represents a cross-section of a 6-feet culvert built of brickwork or concrete, with semicircular arch and an invert, the finished road level being shown 2 feet above the arch. When the bed of the stream has a considerable declivity, and there is consequently a risk of wearing away of the bed during freshets, an invert between the abutments should be provided. The space between the wing-walls, and for a distance along the bed of the stream beyond the newels, should also be pitched to prevent the undermining of the structure.

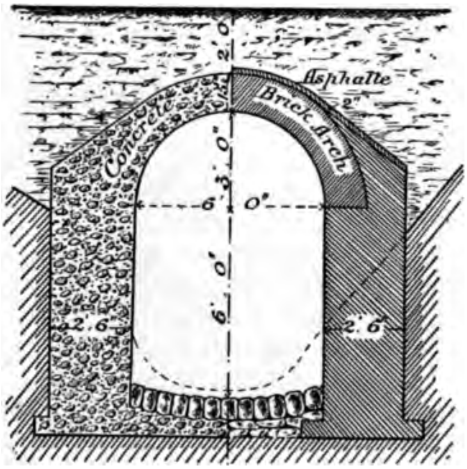


FIG. 34.—Section of 6-feet culvert built with brickwork or concrete.

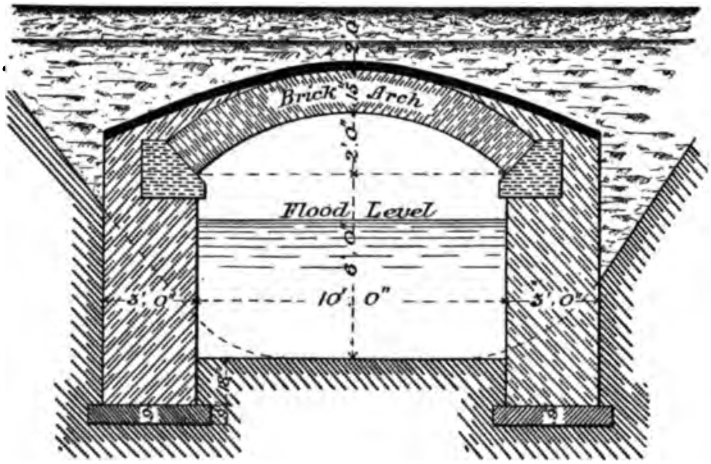


FIG. 35.—Section of 10-feet culvert built with brickwork.

Fig. 35 shows a culvert built of brickwork, the span being 10 feet, and having a segmental form of arch with a rise or versed sine of one-fifth the span.

This arrangement admits of a reduction in the height of the embankment in forming a road compared with a semicircular arch. The stream is assumed to have a gentle current, and the bed not liable to be scoured or worn by freshets. It will also be observed that a springer course of stones is introduced, which affords a more solid and efficient means of starting the building of the arch than would be possible by forming the skew-back with bricks alone.

Fig. 36 shows the principle of steel trough decking applied to culverts, where the raising of an embankment would be necessary if a semicircular arch were adopted. The general arrangement is shown in the illustration, the trough decking occupying a depth of only 8 inches, the space between the ridges being filled with concrete, and the metalling applied to a thickness of 12 inches or an inclusive depth of 20 inches from the under side of beams to the finished surface of the road. With a semicircular arch the finished surface of the metalling would be at least 10 feet 9 inches above the belt or springer course: whereas, using the trough decking, there is a saving of 9 feet of unnecessary embankment, at the site of the structure, and which, if carried out, might cost from £50 to £200.

87. It is advisable to construct catchpits at the entrance to all drains and culverts in localities where, during a heavy rainfall, there is any likelihood of débris or boulders being washed down the stream. They should be about 3 feet deep, and of the full width of the water-course, and be faced with stones built dry or in lime mortar.

88. **Bridges.**—Bridge designing and building is a very extensive subject,

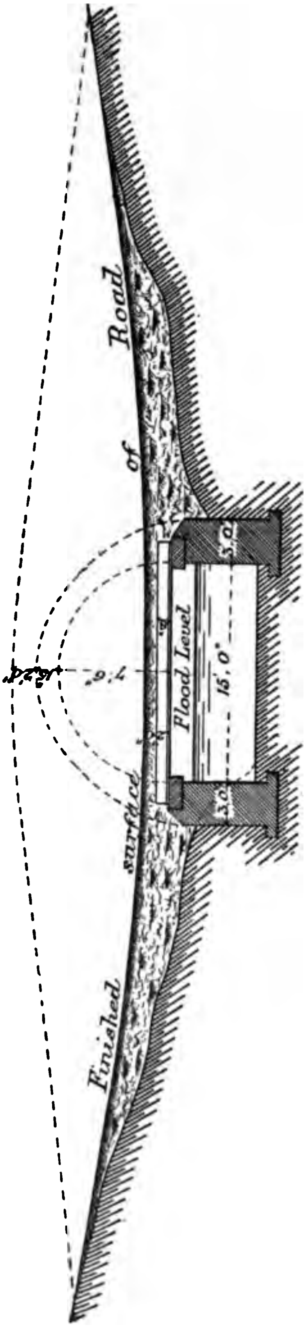


FIG. 36.—Section of 15 ft. culvert and approaches, showing relative levels of road with semi-circular arch and with trough decking.

and embraces the selection and disposition of various materials under different circumstances.

In a work on road making the leading features necessary to be observed in the erection of ordinary structures can only be touched upon. The author refers his readers for further information to the many valuable works published specially on this subject.

89. Materials used for Building Bridges.—Bridges may be built of stone, brick, concrete, cast iron, or steel; or a combined structure of masonry and steel girders may be adopted. Wooden bridges are sometimes erected in localities where timber is available, but generally these are of a temporary nature, and do duty until permanent structures are substituted.

90. Selecting Sites for Bridges.—The selection of a site for a bridge, unless it is predetermined by a line of road which cannot be changed, should be one which affords the greatest security for the foundations, and is otherwise the fittest for economical construction. The centre-line of the bridge should be, if possible, set out perpendicularly to the direction of the flow, and on a straight part of the stream or river to be crossed. Where the locality does not admit of crossing at right angles, the bridge assumes an oblique direction, which, besides adding to the difficulties of construction, greatly increases the cost of erection. When the width of the river to be bridged is great, it may be advantageous to divide the opening into bays by the erection of piers. The position of these must be parallel to the flow of the stream, otherwise the faces of the piers would be exposed to the effects of the water striking against them obliquely; they should be further protected by cut-waters or starlings in order to ward off any floating material such as ice or timber.

91. Waterway of Rivers.—As the area of the waterway will be to a certain extent reduced if piers are erected in mid-stream, provision should be made for this by increasing the total width of opening between the abutments, the object aimed at being to maintain the original force and direction of the current. If the cross-section is diminished it will cause an amount of damming back of the water, which, when it rises to a certain height, will increase the velocity. This may cause damage by flooding the adjoining land, or the bed of the stream may suffer by being worn away. On the other hand, a greatly enlarged cross-section will have the effect of decreasing the current, and causing the bed of the stream to become silted up with deposits from the higher reaches.

What may naturally be expected under such circumstances is the formation of banks, and should these accumulate to any extent, a diminished area or cross-section is the result.

With a series of bays, however, it is possible that only a few of these may be passing the water of the stream in its normal condition. The increased currents induced by the alteration of the bed of the stream will have, during floods, a tendency to scour the bottom, and may eventually prove destructive to the structure by undermining the foundations.

92. Nature of Material of Foundations.—Before deciding on the design of a bridge, it is necessary to thoroughly examine the nature of the material on which the foundation of the structure will rest. The usual method of ascertaining this is by sinking trial-pits to a suitable depth, or by boring, and from the results obtained the class of foundation necessary may be determined. The nature of the different soils in connection with foundations are generally divided into three classes.

The first, or incompressible material composing the strata, includes rock and such other material the stability of which is not impaired when saturated by water.

The second class embraces such material as compact stony soils, dry gravel and sharp sand.

The third class includes all materials which are compressible or spread laterally under pressure, such as ordinary clay, the common earths, soft sand and marshy soils, which are usually in a more or less compact state, and sometimes in a semi-fluid condition.

On a foundation of rock the bed is prepared by levelling its surface, and removing all loose and decayed pieces, reducing all projecting points and filling up all hollows with flat rubble, masonry, or concrete.

Where the stratum composing the rock dips, or inclines to the horizon, it should be stepped, all inequalities being filled in with concrete. The surfaces thus prepared should be perpendicular to the direction of the pressure which the foundation has to sustain, and the courses composing such foundation should have an area sufficient to bear that pressure with safety.

93. Safe Load on Foundations.—The safe load allowed on foundations of the first class ought not to exceed one-eighth of the pressure which would crush it. For general purposes this may be reckoned at 9 tons per square foot on rock of moderate hardness, and 2 tons per square foot on soft sandstone; while rock equal in strength to good cement concrete can safely sustain a load of 3 tons on the square foot.

Foundations on the second class of materials have considerable frictional stability when the stratum is not affected by being saturated with water. These must be excavated to such a depth that the structure will rest on ground not likely to be impaired by the disintegrating effects of frost which has been pointed out under the article on culverts. The safe load or greatest pressure permitted in practice on soils for foundations of this class is generally from 1 ton to 1·5 tons per square foot. The foundation courses, or footings, are usually spread out to a considerable extent beyond the ordinary thickness of the walls they sustain, such breadth being as a rule made 1½ and 2 times that thickness in gravel and on hard clay and sand respectively.

Foundations on materials of the third class present difficulties of a varying nature. The precautions necessary to obtain a safe foundation require in many instances special treatment, involving a correspondingly greater expenditure. On the firmer soils of this class, the usual practice is to lay a bed of concrete varying in depth from 3 to 6 feet, making the breadth of base as wide as practicable. On material which is not homogeneous or is liable to lateral yielding, stability is promoted by enclosing the area of the foundation by sheet piles from 5 to 10 feet long. The soft material composing the soil is then excavated to the required depth, and sand or other suitable material of a stable character spread in layers and punned; this forms to a certain extent a natural sand foundation.

The filling material, so as to ensure greater stability, may be composed of concrete, and although in certain cases this may appear an excess of precaution, it is, nevertheless, advisable to adopt this method of construction when the soil is not of a uniformly compressible nature.

It is necessary, in order to maintain the foundations in a stable condition, that all water in close proximity be got rid of by draining.

94. Timber Platform Foundations.—Timber platforms have been used as an expedient, where the soil forming the foundation was of a wet and soft description, with a view to distribute the weight of the structure uniformly on its surface. This method of construction consists in the laying of heavy timbers at some distance apart longitudinally and crosswise, forming a grating, the spaces between the timbers being filled with material of a stable nature, or with concrete; the whole being surmounted with planks 3 or 4 inches thick fixed to the timbers and upon which the building rests.

Another method of forming timber platforms is to lay several tiers of planks well spiked together. The durability of these foundations is dependent on their being constantly in a wet condition.

95. Piling Foundations.—Where the nature of the stratum is so soft or unstable that any of the foregoing methods cannot be applied, recourse must be had to piling. Bearing-piles of varying length and from 9 to 18 inches in diameter are driven into the soil to sustain the superincumbent weight. These are spaced from 2½ to 4 feet apart, and over the entire area which the structure will occupy. When placed too close the driving in of one pile may have the effect of raising the others. They are driven, in the majority of cases, through the soft material and should penetrate a short distance into the hard stratum underneath.

A safe load on piles under these conditions may be taken at 1000 lbs. per square inch on the area of its head. In the case of a hard stratum not being attainable at a reasonable depth, the piles are then wholly supported in position by friction; a safe load of only 200 lbs. per square inch of area of head is permissible under such circumstances. The driving points of piles are armed with a cast-iron shoe, fixed on by wrought-iron straps, the weight of these varying according to the dimensions of the pile. The head is protected by a wrought iron hoop, which prevents it being split by the blows from the ram of the piling machine. In order to ascertain when a pile has been sufficiently driven home, a test should be resorted to; that given by Professor Rankine is, "No further penetration should take place than one-fifth of an inch by thirty blows of a ram weighing 800 lbs. falling 5 feet at each blow."

The heads of each set of piles are sawn off level to the desired height to receive the platform, which consists of string and cross pieces 10 to 12 inches square, and half-notched into each other, laid directly on the pile heads and fixed by spikes. These wooden beams or cross and string pieces are surmounted by planks 3 to 4 inches thick, on which rests the lower foundation-course of the structure. Previous to fixing the planking, the soil, to a depth of from 3 to 6 feet below the level of the head of the piles, is excavated or scooped out, and the space up to the under side of planks filled in with concrete.

96. Iron and Screw Piles.—Hollow iron piles are sometimes used for a similar purpose, the blow of the ram being transmitted by using a block of wood or dolly on the head of the pile.

Screw piles are likewise used. These are sometimes made of wood, but are usually cast iron hollow cylinders, with a screw blade attached at the foot, having a diameter of from two to eight times that of the shaft of the pile, according to the nature of the soil to be penetrated. The method adopted in fixing the piles in their permanent position is that of turning them around, with the screw attached, by levers fastened to and radiating from a capstan fitted on to the shaft of the pile.

97. Coffer-dams.—The foundations of abutments and piers of a bridge crossing the river require during their construction additional protective works as compared with similar erections on land. Coffer-dams have been employed as a means of assisting in preparing the bed for foundations, and securing them from the action of water. They are generally constructed of guide piles 12 to 15 inches square, spaced at intervals of from 6 to 10 feet, and driven to the desired depth. Two longitudinal waling pieces, notched, are bolted to each side of the guide piles, the lower set being fixed as far down as the water level of the river will permit; the other set should be attached near the top of the piles. Between the guide piles and in the space formed by the waling pieces, sheet piles 3 to 6 inches thick are driven as close together as possible and to the desired depth. At a proper distance apart, generally from 4 to 6 feet, another line of guide and sheet piles are driven parallel to the first row, forming a long narrow trough, enclosing the site where the foundations are to be laid.

The soil between these rows of piles is removed, sometimes by dredging, until a hard compact stratum is reached. The whole space up to, in many instances, a few feet above flood level is filled with clay puddle. When the coffer-dam is complete, the water it contains is pumped out and the ground excavated to the required depth when the foundation courses are commenced, or a thick bed of concrete is spread over the space between the piling.

A single row of guide and sheet piles is sometimes made use of as shown in fig. 37, the scantlings of the timber being heavier than those used for forming a double row. Great care must be exercised, in driving the sheet piles, in order to obtain an impervious coffer-dam, while it must be thoroughly braced internally to resist the pressure of the water surrounding it. These methods of obtaining a foundation, although much practised in past years, and still adopted to a limited extent on small works, have been superseded by the system of caisson foundations.

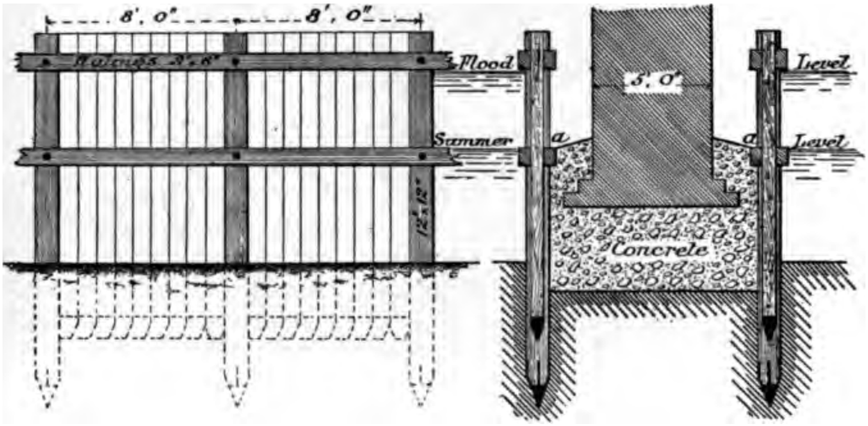


FIG. 37.—Section of coffer-dam showing single line of guide and sheet piles.

The coffer-dams just described are costly to construct, and cause a considerable obstruction in a river or stream, while if, owing to the work not being carefully executed or to the external pressure of the water being great, they are not water-tight, constant pumping is necessary in order to keep the foundation-bed dry during the progress of that portion of the work.

98. Cylinders and Caisson Foundations.—Cylinders or caissons are now extensively used, in building bridges of any magnitude across rivers, as a means of securing a stable foundation, for which purpose they are admirably adapted, and at the same time they are comparatively inexpensive. The superstructure of a bridge may be supported by two or more cylinders joined by arches or ties at a convenient level, on which the abutments or piers are built.

A cylinder, 6 feet or more in diameter, made of cast iron, or of steel built in segments, bolted together, and having the joints made water or air tight, is the form generally adopted. The base, which is sometimes of a greater diameter than the cylinder, is formed with a tapering piece having a cutting edge. The interior of the cylinder is lined with one or more rings of brickwork, which will give it weight, and thereby add to the efficiency of the cutting edge in sinking. The material inside the caissons is removed by dredging, or by the use of mechanical excavators. When they have to be sunk to a great depth, the use of compressed air is invaluable in carrying on the operations. It is necessary to exercise great care in sinking cylinders, so as to retain them in a vertical position, while their location in relation to the line of the bridge demands attention.

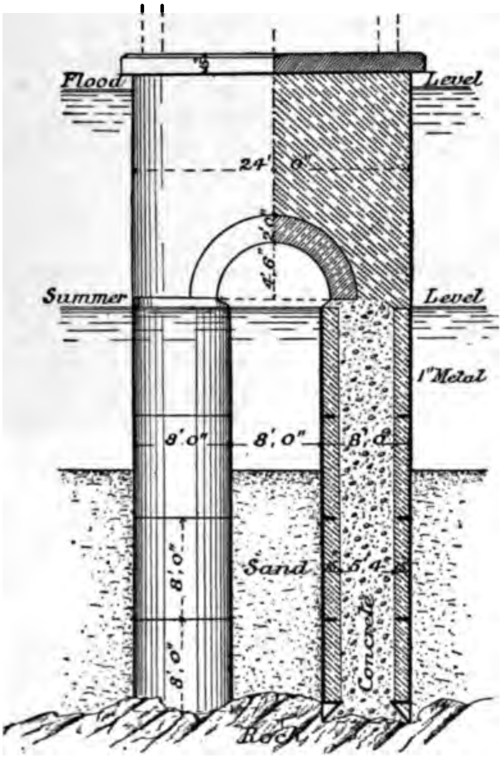


Fig. 38.—Cylinder foundations for piers.

When the excavations have been made to the desired depth, the space inside the cylinders is filled up to a certain height, generally the normal water level, with concrete.

This method of forming foundations with cylinders is shown at fig. 38.

99. Abutments and Piers.—These generally consist of masonry, embracing stone, brickwork, concrete, ironwork, and occasionally timber. It is advantageous in building abutments and piers to reduce the weight, if possible, by forming hollows or narrow archways in them so as to promote economy and stability. These openings must have inverted arches at the bottom to distribute the load over as great a base as possible, and may occupy one-third of the total volume of the wall.

100. Thickness of Abutments.—In practice, the thickness given to the abutments of bridges varies from one-third to one-fifth of the radius of the arch at the crown. In bridges the superstructure of which is formed with girders, the dimensions necessary for stability are regulated by their sufficiency to bear the vertical pressure transmitted by the superstructure.

101. Thickness of Piers.—Piers carrying arches of small span should be broad enough to accommodate the combined thickness of both arches and also allow of a space of at least 6 inches between them. In practice, the thickness generally given to the top of a pier sustaining large arches averages from one-sixth to one-tenth of the span; in viaducts, 'abutment piers' are introduced at each fifth or sixth pier, and generally have a thickness of one-fourth of the span. The object of building abutment piers is to limit the destructive effect of an accident to any of the intermediate sections.

High piers, in addition to the thickness allowed for according to the preceding rules, are generally built with a batter of 1 in 12.

102. Arches.—Arches may be constructed of cut stone, brickwork, concrete, iron, or timber. In form they may, for bridges of large span, be semicircular, elliptical, or a flat circular arc; the latter, with a rise of one-fourth of the span, is greatly made use of in practice, and is considered the simplest and strongest form of arch.

The stones composing the arch of a bridge up to 80 feet span are generally made of the same depth; beyond this span it is essential that the depth of the arch stones towards the abutments should be increased from one-fourth to one-half that of the keystone.

103. Depth of Arch Stones.—The following empirical expression in general use for the depth of the keystone is given by Professor Rankine—

$$D = C\sqrt{r}$$

when D equals the depth of the keystone, C is a constant and r the radius of the arch in feet at the crown. The value of C is as follows:—

TABLE X.

For first-class stonework, ...	C = ·36
For second-class stonework, ...	C = ·4
For brick and rubble, ...	C = ·45

The joints of cut stones or ashlar forming an arch should have a moderate degree of roughness to resist displacement by sliding, and also to aid the adhesion of the mortar.

It is essential that these joints should be properly dressed to template and fitted in position, to test their accuracy before they are finally laid in mortar. The arch stones should be properly bonded, that is, overlapped or break jointed; this has the effect of distributing the pressure and of tying the building together.

104. Brick Arches.—Brick arches may be built of gauged or of common shaped bricks. In practice the latter are generally employed, the arch being built in concentric rings half a brick thick. They are thus all laid as stretchers, a somewhat deficient form of construction; the upper joints should therefore, especially in arches having a considerable rise, be pinned with pieces of slate, and built with cement mortar as tenacious as the bricks themselves, to insure the several rings of bricks being properly connected.

Headers are sometimes introduced at intervals, which embrace one line more of stretchers in the second than in the first course, so that by this means the continuity of the concentric rings is broken.

Brickwork arches are usually built of the following dimensions:—

TABLE XI.

Arches of 12 feet span are made 14½ inches thick.
,, 24 ,, ,, 18 ,,
,, 30 ,, ,, 22½ ,,
,, 40 ,, ,, 27 ,,

The backing of an arch may consist of coursed ashlar, rubble masonry, or concrete, built to a proper level. Provision should be made, in the event of water finding its way from the road surface, to protect the arch and backing by covering the exposed surface with asphalt, and collecting and discharging the water by suitable means through the arch at the lowest points to the surface of the ground.

105. Spandril Walls.—The walls built on the top of the arch rings up to the level of the roadway are called spandrils; these should be of sufficient strength to withstand the lateral pressure of the filling material and the traffic.

In many cases it is advantageous to introduce internal spandril walls built parallel to the external ones on the top of the arch, and covered with flat stones; or small transverse arches may be turned between the walls to support the material forming the bottoming of the highway, the spaces underneath being left hollow. When these internal spandril walls are high, they should be strengthened by building cross walls at intervals.

This method of construction is favourable to stability and lightness, and when adopted the external spandril walls become abutments to the transverse arches, and therefore must have sufficient stability to withstand the thrust imposed upon them. The exterior spandril walls immediately above the keystone of the arch at each side are in most cases finished with a projecting string course, on which the parapets of the bridge are erected.

106. Forming Embankments over Bridges and Culverts.—In forming embanking over culverts and arches of bridges, near abutments, wing-walls, and retaining walls, care must be taken not to injure the masonry by unequally distributed or sudden pressures. As a precaution, dry earth should be spread in thin layers and rammed immediately behind and extended to a distance of about 8 feet from the masonry. It is also essential, when banking over large arched bridges and culverts, to carry it up simultaneously on either side to prevent unequal lateral pressures against the structure.

107. Centering.—Considerable attention must be given to the construction of the centres, an indispensable accessory, on which the arch stones are supported during erection. They are constructed of timber, and consist of parallel frames or ribs, which should be made as rigid as possible. This rigidity is best attained by adopting one of the three following plans stated in Professor Rankine's *Civil Engineering*:—(1) Direct supports, (2) inclined struts in pairs, and (3) trussed wooden girders. For small arches the centres may consist of several light frames or ribs, made up in one or more thicknesses and bolted together. The upper edge is curved to suit the intrados of the arch, and on the top of these ribs planks are laid called *laggings.* Uprights with soles and sills are placed near the springing of the arch, and a similar arrangement is carried out at intermediate points between the abutments or piers where practicable. For light arches the ribs may be erected according to the size of the timber used for the framework, and the distance apart at which the ribs are placed.

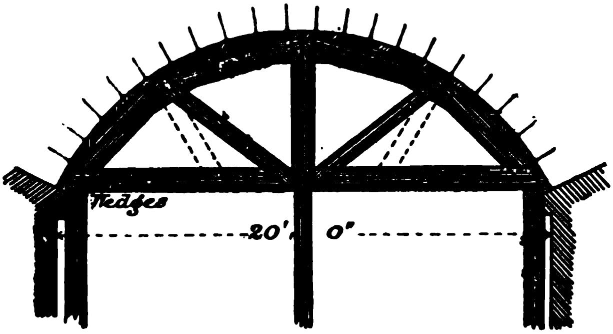


Fig. 39.—Showing scantlings and arrangement of centres for a bridge of 20 feet span.

Fig. 39 shows what would be suitable for an arch of 20 feet span and of brickwork 18 inches thick. The ribs may be spaced at from 3 to 5 feet apart, according to the weight of arch, the laggings being 1½ inch thick in the former case, and 2 inches in the latter. The struts are placed as shown in the figure, or they may be fixed at right angles to the arch, as shown by the dotted lines. The centering shown in fig. 39 has a support midway between those at the abutments. With a span of 15 feet similar scantlings of timber may be used, but without the centre support. Centres for large arches are constructed of heavy timber, and are sustained either on intermediate supports across the span, or, when this is not practicable, on the foundations of the abutments or piers at both sides. In the former case, with arches of considerable span, the curved parts of the ribs carrying the laggings are supported by struts sometimes placed perpendicularly to the intrados, resting upon horizontal beams fixed on upright timbers, or piles for river work, carried up from the ground level. These struts may also be placed in a vertical position and be strengthened by diagonal bracing to counteract any tendency to lateral flexure. With this form of centre the frame is not liable to change shape should the building of the arch stones be carried up to a greater extent on one side than on the other during construction.

In the other case mentioned, where an intermediate support for the centres cannot be fixed sufficiently near each other, a system of inclined struts in pairs or trussed wooden girders should be employed, but this is a complicated arrangement. Stiffness being essential, polygonal frames and timber arches should be avoided, owing to their flexibility.

108. Wedges and Striking Blocks for Bridge Centres.—It is necessary, when erecting a centre, that provision be made for its being easily removed when the arches are completed. The simplest method of accomplishing this, especially in centres of small bridges, is that of placing double wedges having a taper of 1 in 6 or 1 in 8, on the sills immediately under each rib or centre, as shown in fig. 40. For large spans wedge-shaped steps are employed called *striking plates.* It is of the utmost importance, especially in bridges of very long spans, that the centres should be lowered gradually in order to allow the arch to take equal settlement.

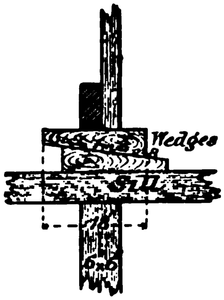


Fig. 40. — Details of lowering wedge for centres of small span.

The wedges should have a long taper of about 1 in 10, and be marked in a distinctive manner so that each rib may be lowered by an equal amount at the same time. The time and extent of easing and striking centres depend on the size and weight of the arch, temperature, composition of the mortar, and the class of masonry of which the arch is constructed. Centres may be eased immediately after the arch (built with lime or slow-setting cement mortar) is loaded to stability, while the centres should be struck in from five to eight days. The same remarks apply generally to small arches built in cement, only the centres should be struck sooner; in large arches, however, built with quick-setting cement mortar, it is considered inadvisable to ease the centres at all. The cement in the portion of the work first built will have set before the completion of the arch, and any easing would injuriously affect the setting of the cement in the portion of the arch which was executed last. Disturbance of the work by vibration should be guarded against, as it destroys the setting power of all kinds of mortar, especially of cement. The centering for concrete arches should not be disturbed for at least fourteen days after finishing the concrete.

Iron pipes 1 foot long filled with dry sand, and provided with a cylindrical block of wood fitting into the top, placed under the ribs of the centering, are sometimes used as a substitute for wooden wedges in easing and striking centres. The process of lowering is accomplished by allowing the sand to run out of the cylinders as required.

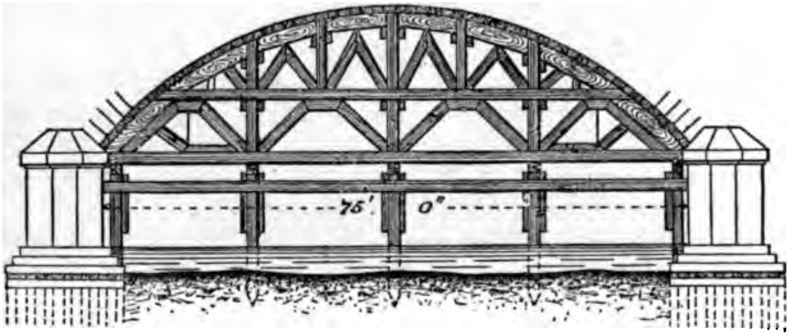


FIG. 41.—Centre for arch of a bridge over the river Don.

109. Centres for Arches of Bridge over the river Don and London Bridge.—The centering shown in fig. 41 is Telford's design for a centre with intermediate supports, used for a bridge over the river Don, of which the span is 75 feet, while fig. 42 shows the pier centering of trussed girders adopted in the building of London Bridge.

The latter illustration shows that one-fourth of the span at either side was directly supported by piles and diagonal bracing. The rib across the middle half of the span was formed of a diagonally braced girder of great stiffness, the depth being one-fourth of its span. The striking plates and wedges by which the centre is lowered after the completion of the arch are shown in the figure, *a* being the upper plate, *b* the lower plate, and *c* the compound wedge, which is kept in position by the cross wedges *d*.

110. Timber Bridges.—Bridges erected with timber supports and superstructure are now an almost obsolete form of construction in this country, except for temporary purposes. Timber beams resting on abutments or piers of masonry are used to a limited extent when the span is small and the traffic unimportant. In those countries where timber is abundant many large bridges have been erected with this class of material, and when properly protected and painted are said to last about twenty years. The simplest manner in which timber can be applied, when the supports are of masonry, is in the form of beams or string pieces with cleading fixed on the top to carry the roadway. When the span exceeds 8 or 9 feet, struts are generally introduced, as shown in fig. 43. Another form of construction suitable for spans up to 30 feet is shown in fig. 44, and may be used for bridges carrying light traffic. Beyond these spans different forms are employed, such as trussed girders composed principally

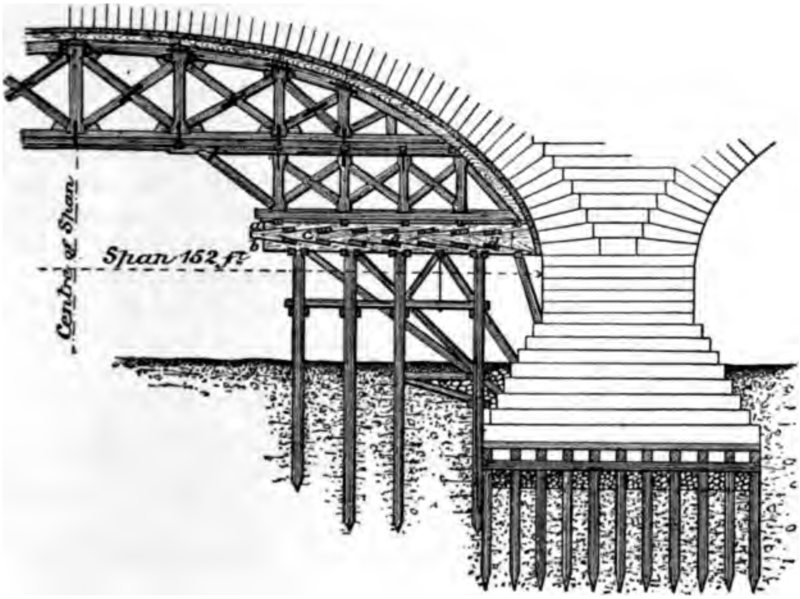


FIG 42.—Centre for arch, London Bridge.

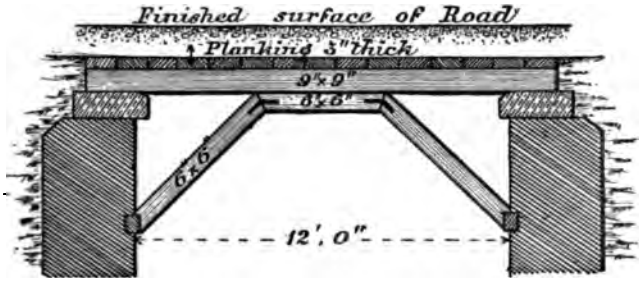


FIG. 43.—Timber bridge for small span.

of struts and ties, with parallel top and bottom beams, or in the form of an arch.

Timber bridges, owing to their perishable nature when subjected to the influence of alternate wet and drought, should not be made use of except when other suitable materials are not available. The annual cost of repairs upon timber bridges becomes a heavy item, and in the course of a few years will equal, if not greatly exceed, the expenditure which the building of a permanent structure of stone or brick work would entail.

111. Iron and Steel Superstructures.—The superstructure of bridges formed with iron or steel has to a great extent superseded the ordinary masonry arch, in bridges of long span, or where the line of the bridge is at a considerable angle to the object crossed. The employment of cast iron is limited to bridges having short spans, the roadway being carried by jack arches built between and springing from the lower flanges of the beams; the arching being generally made 9 inches thick, and covered with a ¾-inch layer of asphalte or other impervious material. The space between the beams and over the arches is filled with concrete, broken bricks, or other material of a like nature, up to the level on which the metalling is spread.

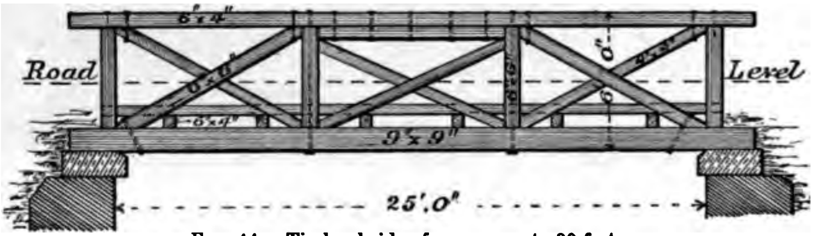


FIG. 44.—Timber bridge for span up to 30 feet.

The thrust on the outside or face-girders, when jack-arches are employed, is provided for by means of tie-rods 1½ to 3 inches in diameter, placed at intervals across the bridge from 5 to 8 feet apart, which bind all the longitudinal girders together. This method of construction is illustrated in fig. 45.

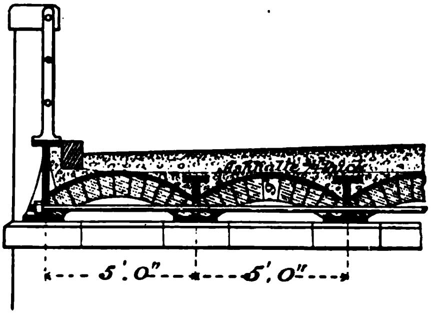


FIG. 45.—Cross-section of bridge formed of cast iron beams and jack-arching.

The superstructure of most bridges is now constructed of wrought iron or steel. The plate girder of uniform depth or hog-backed shape has been greatly used, and was the form employed almost exclusively previous to the lattice type being introduced.

The plate girder is still made use of in spans up to 60 or 70 feet; beyond this it is more economical to employ girders of the lattice type, which may have parallel booms, or be constructed on the bowstring principle; sometimes, however, they are built in the form of an arch.

When the head-room or height to the under side of the girders in crossing an existing line of communication, railway, canal, or navigable river is limited, only outside main girders are employed to carry the roadway. When, on the other hand, no such restriction is involved, the roadway may be carried on the top of a series of plate or lattice girders having a uniform depth. In the former case cross girders, of the plate or lattice type, are required, and extend between the main girders to the lower flanges on which they are fixed. These transoms or cross girders are built with a camber similar to that of the rise of the transverse section of the road; they are spaced from 6 to 10 feet apart, on which bearers running parallel to the main girders are fixed, and on the bearers convex buckle or corrugated iron plates are riveted, which, extending the whole width across the bridge, completes the superstructure. These plates are generally covered with asphalt, but concrete, composed of cork and bitumen, is also made use of on account of its lightness, while fine cement concrete is at times employed to protect from moisture the ironwork on which rest the materials composing the road.

112. Steel Trough Decking.—Steel trough decking is now extensively used in forming the floor or deck between the main girders of bridges, and may be fixed on the top or to the web and lower flanges of these girders. This form of decking is gradually superseding that of cross girders and buckle plates in the construction of the steel superstructure of bridges. Trough decking may also be used, not in the form of a cross girder but longitudinally, in which case the outside or main girders are dispensed with, and their employment insures a considerable saving on the first cost of constructing bridges up to a span of 36 feet. They are designed to carry with safety live or moving loads, comprising the weight of road-rollers and of traction-engines, in addition to the ordinary loads to which road bridges are subjected. The cross-section of a road bridge with this type of superstructure is illustrated in fig. 46. The dimensions shown are suitable for spans of from 16 to 20 feet; the weight of the steel decking for these spans is from 25 to 30 lbs. per square foot respectively.

113. The gradients of the approaches to many existing bridges and culverts could be greatly improved by substituting trough decking for the rubble arches of which many of these are built when they fall into a state of disrepair and require renewing. The relative cost of building an arch of brickwork in cement, including haunches, spandrils, and centering, for a bridge having a span of 20 feet, would be about 3s. 2d. per square foot of area covered; and for trough decking, assuming that the abutments are built to the same height in either case, 2s. 8d. per square foot. The saving effected in the construction of the superstructure of such a bridge 16 feet wide would be £15 in favour of steel trough decking.

114. Protecting Dangerous Places.—All roads at dangerous points should be protected to prevent accidents to pedestrian and vehicular traffic. This, as a rule, applies more forcibly to precipitous hillside and mountain roads. Road authorities are under an obligation to perform the work necessary in carrying out these protective works, while the roadsides on level ground are fenced by the proprietors through whose land the highway passes. Many methods are in use for accomplishing this.

Earthen mounds are the most economically formed, but are generally in time raised too high by the roadside accumulations being heaped upon them, whereby free circulation of air on the road surface is prevented. The outlets or cuts for discharging the surface drainage of the road require special attention where this form of protection is adopted. Parapet walls of stone built dry are an efficient and economical means of protecting a road, where such material is available. In sidelong cuttings, where retaining walls are a necessity, the parapet walls are formed by continuing these to a proper height. They should have a thickness of at least 18 inches, and be 3 feet 6 inches to 4 feet high, finished with a rough cope set on edge, while the outside joints and cope should be pinned and pointed with lime mortar. The most common fence, however, is that of the quick set hedge, planted on the top of a raised mound made from the excavations in forming the ditches. It makes a good protection after the lapse of some time, but requires in the interval a considerable amount of attention. An open post and rail fence answers the purpose very well, while wooden and iron posts to which plain galvanized iron wires are attached is the method adopted in districts where building stones cannot be conveniently obtained. The great objection to stone fences is that, being liable to decay and damage,

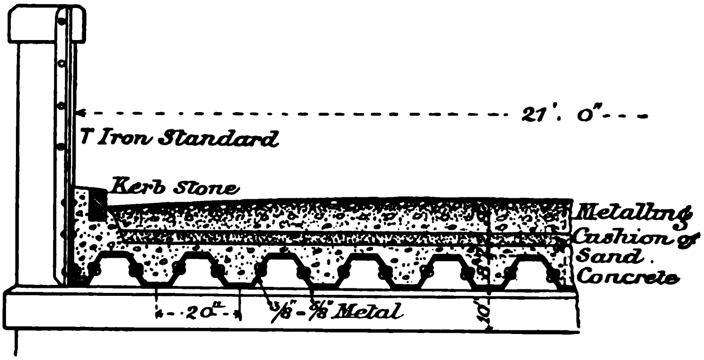


FIG. 46.—Cross-section showing arrangement of steel trough decking as applied to bridge work.

they are expensive to maintain. So far as the durability of the road surface is concerned, this is best promoted by having open fences, as by this means of protection the beneficial influence of the sun and wind in producing evaporation is not lessened; while with close fences, such as stone walls and hedges, especially if they be high, the beneficial effects mentioned are diminished to a considerable extent.

115. In districts where snowstorms are prevalent during the winter months, the existence of close fences alongside a highway, apart from those for protecting dangerous places, is a source of considerable expenditure in opening the roads for traffic after a snowdrift. Where walls and hedges form the boundary line of a road it is not an uncommon experience to encounter a snow cutting of 6 feet in depth the full width of the roadway, and extending in many instances for miles, while the adjoining fields are comparatively free from snow.

In the author's experience, the cost of clearing snowdrifts has amounted, on many occasions, to from £400 to £600 over a district of between 200 and 300 miles, and this expenditure in all probability would have been saved, or at all events greatly reduced, had open fences existed instead of walls and hedges. Besides the heavy cost thus entailed, considerable damage is done to the road surface by the melting snow, especially where there is heavy vehicular traffic. It is doubtful, even on consideration of the preceding facts, whether any improvement may be looked for in the direction indicated. The protection afforded to farm stock when grazing, and the capital expenditure already involved in providing these close fences, remove to a remote date any probability of a change, or it might be said reform, being brought about.

CHAPTER IV.

ROAD-MAKING MATERIALS.

116. Not only does the science of geology enter largely into consideration in making new roads in many localities, as indicated in the last chapter, but to a greater extent in the selection of the most suitable spots for opening the necessary quarries for supplying materials for making new roads and streets and the maintenance of existing highways. Chemistry and petrology also contribute their share to the knowledge necessary for the proper scientific study of the materials for road-making purposes. Hitherto road-stone has been selected, in the first instance, from previous knowledge of this class of material acquired by the engineer or surveyor who can determine with a certain degree of accuracy what may prove to be a suitable stone. Observation of the behaviour of the stones in a road is certainly more convincing, but time is necessary for such a trial, and it may, after all, turn out to be deficient in durability. Experience shows that in many instances, even in the same quarry, remarkable differences exist in the quality of the rock which, to all appearance, is of a similar nature, and it is only by a microscopical examination of the rock that these peculiarities and the diverse wearing properties of different rock-types can be detected.

To the science of petrology, therefore, must the road engineer and surveyor look for that assurance, combined with a study of the physical tests and his own knowledge of the actual use of some reliable types of road-stone, which will ensure the most suitable and durable material being selected for any particular road.

117. The essential qualities of a good stone for paving-setts or macadam may be stated as follows:—**Paving-setts**: hardness, toughness, durability; uniformity of wear, retention of a rough surface under traffic in all conditions of weather. **Macadam**: hardness, toughness, durability; retention of a rough surface (though this does not apply to the same extent as in paving-setts), and, in some degree, the property of binding necessary to maintain cohesion under varying conditions.

Hardness.—This, an essential quality, may be described as that resisting property which a solid offers against any displacement of its parts or abrasion of its surface.

Toughness.—This is also an essential quality, and is that property which admits of the constituent minerals yielding to a small extent without separation of the parts, and enabling the stone to resist fracture when struck with a hammer, or by the blows and concussions which obtain at the surface of a road or sett-paved street. Stone for road-metalling purposes may not only be hard, but brittle, and, consequently, deficient in cohesion or toughness, as in quartz and flint. In the case of these materials the stones crumble under traffic, owing to the hard grains being insufficiently bonded together or mutually attached. This defect, to a certain extent, applies in the case of the intrusive and volcanic rocks which have a comparatively high acid composition.

Durability.—This quality, under conditions of wear, depends on the hardness and cohesion of the rock, and also on the chemical stability of the constituent minerals. The tendency to decompose or weather is present in most rocks when brought under the oxidizing influence of air and water. The question of the resistance of a road-stone to chemical agents is, as might be supposed, of great importance. In addition to the decomposing effect of air and water on most rocks, paving-setts and road-metal are further subjected to the solvent action of impure surface water charged with salts and organic acids.

The softening or partial decomposition of a road-stone by these chemical changes has generally been regarded as a destructive element in road maintenance. It appears, however, from recent investigations that the chemical decomposition is not so destructive as road engineers formerly imagined it to be. Notwithstanding this, it can hardly be doubted that the weathering properties of a stone are determined by resistance to chemical action. And although this may be, in some instances, slow and not appreciable on the surface of a road which is renewed from time to time, the internal structure, by the solvent action of surface waters percolating through the metal coating under abnormal conditions of weather, must be adversely affected.

Binding or *Cementitious Properties.*—This quality depends to a great extent on the toughness of a rock and its resistance to spalling and fracture. Road-stone showing these characteristic features has generally a rough-fractured surface which enables it to retain its position in the road better than a stone having too smooth a surface. Road-metal consolidated by using chips and dust of the same material, especially if the rock is of the more acid varieties of the volcanic and porphyritic groups, is generally deficient in cementitious properties; it therefore becomes necessary to employ binding material of a slightly clayey nature to maintain cohesion. The dust produced at the surface of a macadamized road through wear may, under certain conditions, filter into the body of the road during wet weather, but more generally it is blown off the surface by high winds or removed in the form of mud.

118. The frictional wear, especially with road-stone of a brittle nature, is considerable. Traffic during extreme conditions of weather causes movement and rubbing of the stones, which wears off their sharp edges, and become rounded. This must lead to disintegration of the road crust; especially is this the case when binding of a siliceous nature is made use of deficient in iron oxides or other cementitious matter. It may be mentioned in passing, though the matter will be referred to later, that, in the author's experience with different types and varieties of road-stone, the acidic andesites and felsites create less mud and dust than basic andesites, dolerites, generally, and some basalts and granite.

119. The distribution of rocks over the British Isles suitable for road-making purposes furnishes a remarkable geological study of the operations of Nature in the past. In most localities stone of some kind, more or less suitable for the purpose in view, is invariably found, and a glance at the geological maps will indicate this, enabling the road engineer to investigate the varying features of particular districts.

Igneous rocks, for the most part, are resorted to for the supply of paving-setts, kerbs, channels, and road-material. These rocks appear in the crust of the earth as rock masses, veins, dykes, and bosses, and vary greatly in mineralogical composition, chemical stability, and physical strength. Metamorphic rocks are also made use of for road-making purposes. The sedimentary group of road-stones embrace quartzite, sandstone, limestone, chert, and flints, many of which possess good qualities under certain conditions. This class of road-stone is, however, on the more important roads at least, being superseded by the igneous types of rock which possess the necessary qualities.

The durability and other properties requisite in a road-stone, and upon which its value depends, are influenced by the mineralogical composition and petrological character of the rock-types suitable for this purpose. The resistance to chemical decomposition of the constituent minerals is also a characteristic feature, while the rock structure, or the manner in which the component parts are aggregated together, is an important factor.

The igneous rocks, formed by consolidation from a molten state, differ in character from one another, due partly to the composition of the magma and partly to the condition attending its consolidation. The latter condition is of a diverse nature—the cooling of the plutonic rocks has been a slow and gradual process, favourable to the perfect development of the crystalline forms of its constituent minerals, while in that of the volcanic group the rocks have consolidated under superficial conditions, that is, by comparatively rapid cooling under low pressure. These diverse conditions naturally produce different structural characteristics, and the rocks possess varying differences in coarseness and fineness of texture and the mutual arrangement of the component minerals. Rock for road-making purposes depends not so much on the constituent particles for durability as on the strength of the base or matrix by which these particles are held together. The composition of a rock is indicated to some extent by the essential minerals, while the accessory ingredients go a long way towards determining the fitness of a stone for road-making purposes. It is therefore necessary to take into account the relative abundance of these minerals, which form the bulk-analyses, though a mere enumeration of the minerals does not give a very precise indication of the nature of the rock from which road-stones are to be procured.

The chemical stability of different minerals varies considerably, and the amount of these unstable constituents which are decomposed by the oxidizing influences of air and the chemical waters which prevail on the surface of a road should be carefully determined. The effect of passing traffic on road-stones composed to any extent of unstable minerals is that they will, in due course, rapidly disintegrate into a clayey residue, forming mud in wet and dust in dry weather.

120. The more important essential and accessory minerals of which road-stones prepared from the igneous rock-types are composed will now be briefly described.

Quartz.—Quartz is crystallised silica, and occurs as isolated crystals and crystalline granules in many rocks. In granite it merely fills up the spaces between other crystals, and has no definite crystalline shape. Silica is an abundant mineral in most road-stones, and being of great hardness, is practically indestructible. The crystals, in microscopic slices, are usually cracked; the bounding edges are, however, generally well defined, and there is practically no trace of alteration in their composition.

Felspar and *Mica.*—These occur in many different varieties, and are essentially silicates of alumina, with varying proportions of silicates of potash, soda, lime, or other bases. Potash felspar, or orthoclase, is much more durable than the plagioclase variety, containing a large proportion of soda and lime. The potash form of mica, muscovite, is much more durable than the black ferro-magnesian mica, biotite. These minerals occur in granite as essential constituents, and are components in a greater or less degree in most of the other igneous rocks.

Augite and *Diallage.*—The pyroxenes, of which augite and diallage are the most important as rock-formers, are essentially silicates of lime and magnesia, these bases being replaced at times by alumina and oxides of iron, etc. Augite is an essential constituent in the basalt family of rocks. Diallage, a variety of augite, is an essential mineral in gabbro.

Hornblende.—Hornblende is the only mineral in the amphibole group of any importance as a constituent mineral in the rock-types under review. It is an essential constituent in syenite and diorite, but is met with as an accessory mineral in many other igneous rocks.

Olivine.—This mineral is a silicate of magnesia and protoxide of iron, and is an abundant constituent in the greater part of the basalt family of rocks or basic lavas.

The accessory minerals are numerous, and, besides those described as essential minerals, which exist as secondary constituents at times in many igneous rocks, include hematite, magnetite, ilmenite, pyrites, etc. The metallic oxides are favourable to a road-stone in some instances, but generally they are a source of weakness, especially if present in large quantities.

121. In addition to the composition and relative abundance of the essential and accessory minerals, and the manner in which these are aggregated together in the different types and varieties of igneous rocks, characteristics of a diverse nature, more or less favourable, generally exist in stone for road-making purposes. Some of these characteristics, for instance, are fluxion or flow structure, cleavage, freshness of the minerals, alteration, decomposition-products, all of which require careful investigation in order to determine whether one or other of these structural peculiarities tends to improve the stone, or whether their existence is a source of weakness. Rock structures having fluxion phenomena, including flow lines, parallel orientation of phenocrysts, and banding, are features peculiar to some rock-types, particularly in the volcanic groups, and especially in the andesite family. This structural feature, if it exists to any extent, impairs the compressive strength of a road-stone, and is therefore not favourable to good resisting properties. The presence of natural microscopic planes of weakness caused by the disposition of the minerals induces a tendency to split, or shows natural cleavage. Freshness of the constituent minerals is advantageous, but certain forms of alteration of the original components appear to improve the stone as a whole.

The alteration of augite to hornblende is beneficial, and that of the felspars, the alteration-products of which are epidote, albite, quartz, and mica, does not appear to adversely affect the rock; but the decomposition-products calcite, limonite, and kaolin bring about injurious results. Generally the alteration of the felspars and some of the ferro-magnesian minerals apparently increases the compactness and toughness of rocks. On the other hand, alteration in the sense of decomposition, so that disintegration ensues, makes rocks so affected unfit for road-making purposes. For instance, the decomposition of augite and olivine into soft substances such as serpentine, chlorite, and carbonates, decreases their wear-resisting properties, more especially if these decomposed minerals occur in numerous large units.

The ophitic structure in many of the varieties of the basaltic group of rocks, which is a factor of importance in the wearing properties of road-stone produced from these rocks, depends entirely on the freshness of the augite, as the stability of an ophitic rock depends on this mineral.

Generally the fineness and evenness of grain of rocks used as road-stones are advantageous compared with those rocks the component minerals of which form a coarse aggregation, but in these particulars there are notable exceptions.

122. The more important rock-types used for paving-setts and road-stones will now be described. The classification employed is that usually adopted in petrology, viz., Plutonic, Hypabyssal or Intrusive, Volcanic, Metamorphic and Sedimentary rocks.

Plutonic Rocks.—*Granite* is a plutonic igneous rock, and is met with, in general, in large rock masses. This distinctive feature of granite, as in other rock types of deep-seated origin, points to slow cooling and consolidation under great pressure. It is an even-grained, holocrystalline rock, the texture being comparatively coarse, or from medium to coarse. Granite is composed essentially of felspars, quartz, and some form of mica or a ferro-magnesian silicate, in addition to the accessory constituents, aggregated together in a thoroughly crystalline-granular manner. The felspars form the greater part of a granite, a potash- or soda-bearing felspar, commonly occurring together, and the durability of the rock depends largely on their nature; the decomposition-products are kaolin, minute flakes of mica, and, in the lime-bearing varieties, some epidote or calcite. Quartz, in nearly all cases, acts as the ground-mass, and as it was the last constituent to be solidified, it is moulded around the other grains. An important feature in connection with granite, which is sometimes an advantage and at times the reverse, is, in the case of paving-setts, that the felspars are compactly interlocked with the quartz; and the more compact and fresh is the granite, the more likely it is to prove satisfactory in point of durability.

The predominant mica in granite is of the muscovite variety, though the dark brown or black variety, biotite, is also found to be present. Mica is of a soft nature, and is readily split into thin lamellar plates. The dark variety, or biotite, is rich in iron oxides, and is often found in a more or less decomposed or transformed state. It is of inferior chemical stability to the white or muscovite variety, the latter being, next to the quartz, the most stable constituent of granite.

Hornblende, which is a constituent of some importance in rock for road-stones, owing to its toughness, is common in some varieties of granite. Of the numerous accessory minerals iron oxides and pyrites are the most important.

There are many leading types of granite depending on the characteristic mineral after felspar and quartz, such as muscovite-, biotite-, hornblende-, and augite-granites. The texture of these varies considerably from coarse crystalline masses to fine granular rocks, which pass into elvans and porphyries, the quartz-felsite or quartz-porphyry of the hypabyssal group. These latter rocks are chemically nearly similar to granites, but they differ materially in structure from them.

Syenite.—This rock, a variation of the granite type, is an even-grained holocrystalline aggregate of orthoclase felspar and a ferro-magnesian constituent in the form of hornblende or augite and, at times, biotite in addition, and various minor accessories. Quartz is a subordinate constituent. The hornblende-granites pass almost imperceptibly into syenite and diorite.

Diorite.—This is a similar rock to the preceding, the only difference being in the kind of predominant felspar, plagioclase taking the place of orthoclase. These rocks are largely used as road metal, and those having the component minerals fine-grained and compact are satisfactory and durable compared with those of coarse grain, which quickly decompose and form mud in wet weather. This type of rock, containing free quartz, is known by the name of quartz-diorite.

Gabbro.—This rock is holocrystalline, and the essential minerals are a lime-soda felspar and a pyroxene. These rocks are intermediate and thoroughly basic in composition. The gabbros and norites show considerable variation in mineralogical constitution, and the texture varies from medium to coarse-grained. There are many varieties of this rock, such as hornblende-, olivine-gabbros.

Hypabyssal Rocks.—Under this head such rocks as the Acid Intrusives, Felsite, Porphyries, Porphyrites and Diabases are included. The acid intrusives are porphyritic in character; the ground-mass may, however, vary from holocrystalline to partly crystalline and partly glassy. They are composed of felspars rich in alkali and usually quartz, while ferro-magnesian minerals and free iron-ores occur in very small quantities. The quartz-felsite or quartz-porphyry rocks are composed of a mixture of orthoclase and quartz as essential constituents, little or no mica being found in their composition. The former rock is generally very compact in texture, being intimately mixed so as to present a homogeneous matrix, while that of the latter, or quartz-porphyry, is characterized by continuous crystals. Triclinic felspars occasionally occur in these rocks, while the minerals, mica and hornblende, accompany the essential constituents; apatite, magnetite, and pyrite being at times met with as accessories. The colours of these rocks vary from flesh-red, purple, yellow to slate-gray, depending chiefly on the felspar. Mica and hornblende impart to these rocks dark-grey, brown and greenish tints. These rocks, unlike granite, occur in dykes or sheets, are produced from an acid magma, and are, for the most part, too hard for use as paving-setts, developing, as they do, a tendency to wear under traffic to a smooth and slippery surface.

Diabase.—The diabases, like their plutonic equivalent, gabbros, are holocrystalline and typically non-porphyritic; they are finer-grained, however, and differ in structural and other particulars. The felspars vary from oligoclase to labradorite. The pyroxene constituent is augite, although in some instances bronzite, hornblende, brown mica, and quartz are found. Olivine, generally found in idiomorphic crystals or grains, occurs in most rocks of this type, and the iron-ores, usually ilmenite and magnetite, occur abundantly. The decomposition-products are calcite-dust, mica, and epidote in the felspars; fibrous or scaly aggregates of serpentinous and chloritic substances; and the usual characteristics of the metallic oxides. There are different varieties of this rock, as augite-, hornblende-, mica-, enstatite-, olivine-, and quartz-diabases. The structural peculiarity common to many rocks in the basaltic group, which resemble the dolerites in many other respects, and which gives cohesion to the crystalline particles, is present in this rock and known as ophitic diabase.

Volcanic Rocks.—Under this group are included the andesites and basaltic family of rocks.

Andesites.—These rocks are of intermediate composition between the preceding and those immediately following. There are acid and basic varieties; the former are rich in quartz, and are known as dacites or quartz andesites. The grain is fine, and the characteristic minerals of the ground-mass are a soda-lime felspar porphyritically developed and one or more ferro-magnesian minerals. The varieties, according to the dominant constituent, are distinguished as hornblende-, mica-, augite-, and hypersthene-andesites. The felted structure of the ground-mass in typical pyroxene-bearing andesites is advantageous to durability. On the other hand, however, flow-structure, peculiar to many igneous rocks, is evident in andesite, which, if sufficiently pronounced, is a source of weakness in a road-stone. The decomposition-products of the felspars are calcite, finely divided kaolin or mica, epidote; and those of the ferro-magnesian minerals give rise to chlorite, magnetite, carbonates, etc.

Basalt Group of Rocks.—The basalt family of rocks includes dolerites, the texture varying from finely-crystalline to coarse-grained. They consist of highly basic felspars, as labradorite and anorthite, together with augite, olivine, and magnetite or titaniferous iron with apatite and, sometimes, sanidine and nepheline. The augite in basalt plays a similar part to that taken by hornblende in the rocks described above, and is also a constituent mineral of most of the following series. These rocks occur as dykes, veins, intrusive bosses and sheets, and sometimes present columnar structure. *Basalt* is generally close-grained and compact, the dark colour being chiefly due to the large proportion of magnetite, which also contributes to its high specific gravity. *Diabase* consists of practically the same minerals as basalt, but differs in some other respects, and has therefore been placed in the hypabyssal group of rocks. *Dolerite* is a term given to the more coarsely crystalline varieties of basalt. The tendency to crystallization is much stronger than with the more acid families of lavas, the structure being holocrystalline and the texture coarse compared with the generality of lavas; they are mostly porphyritic. The characteristic structures are granulitic and ophitic; the latter feature has been observed in the previous rocks, which is advantageous to durability. The alteration of augite to hornblende is important, but that of olivine to serpentine is, in some instances, unfavourable, especially if it occurs in numerous large units. The durability of this variety of the basaltic group of rocks is very variable, however, depending in a great measure on the freshness of the ferro-magnesian minerals and silicates. The ophitic structure depends on the augite being fresh, otherwise this beneficial property is lost and the rock is then of little value as a road material, except, perhaps, for unimportant roads. The decomposition effect in this class of rocks will be noticed more fully under par. **125**, 17.

Metamorphic and Sedimentary Rocks.—This class of rock embraces Hornfels, Mica-schists, Quartzites, Sandstones, Limestones, Flints, etc. The hornfels vary in structure greatly, and are somewhat brittle; when hornblende is an important ingredient the rock is preferable to those composed of constituents of a less tough nature. *Mica-schist* is essentially composed of quartz and mica disposed in layers which give it a stratified appearance. It is used as a road-stone in the West Highlands of Scotland and in Wales on light-trafficked roads with fairly good results.

The *quartzites*, of all other descriptions of rock in the sedimentary group, are distinctly superior as material for road-making purposes. This result is mainly due to the fact that the grains are completely cemented together with quartz; these stones are, however, very brittle. Most of the *limestones* have been largely, and are still, employed as road-stone in many counties in England. The durability of these rocks is influenced by their porosity, which varies with the compactness and crystalline texture. The Carboniferous or mountain limestone is the best of this group of rocks for macadam. When subjected to heavy vehicular traffic this road-stone makes much dust in dry and mud in wet weather, the latter being of a very greasy nature. Alternate frost and thaw renders this material practically useless on roads thus affected. *Flints*, especially those which have been weathered, give good results, but are exceedingly brittle and unsuitable on roads bearing heavy traffic. Chert, gravel, slag, and many other kinds of material are used, but most of these, including the sedimentary group, and some varieties of the plutonic, hypabyssal, and volcanic groups of rocks, are doubtful in regard to durability.

123. In selecting material for the purpose of road-making, the essential characteristics mentioned on p. 94 should form an excellent guide, though practical experience assists materially in judging the quality of any particular rock. The mere examination of a hand specimen is not always sufficient to determine the mineralogical composition in regard to alteration-products, chemical stability, or in respect of those properties which go to make a durable road-stone. Hitherto that experience, combined with an experimental trial of the stone itself on a section of road, more especially when opening a new quarry, appears to be the only rational and satisfactory means of determining the point. Comparison by this means may be made of different kinds of road-stone, and the results obtained, after years of wear on a road over which a known amount of wheel traffic has passed, compared with those recorded on another section of road similarly situated and maintained for years with a material of recognized quality. This process takes time, however, which is a serious drawback when the exigencies of the case demand that material from a new source has to be found and tested within a reasonable period of time.

124. To assist those concerned in road work, physical and other tests of road-making material have been in use for some years past, and, apart from being extremely interesting, have proved to be of assistance generally. The results obtained have, however, only a relative value, while in many instances the conclusions arrived at are extremely misleading, unless taken in conjunction with some well-defined characteristic as shown by a microscopical examination of the road-stone.

Road-stone Tests.—These are generally known as the abrasion, drop, absorption, weathering, crushing, and cementation tests, and the microscopic examination of the road-stone.

Abrasion Test.—The abrasive resistance of road-stone to withstand the effects of traffic depends principally on the toughness of the rock, and, to some extent, on its hardness. The difficulty in physical tests of this nature is that percussive attrition and internal abrasion under certain weather conditions cannot be artificially produced in a satisfactory manner. The most useful machine for this purpose is perhaps that designed by Mr T. de Courcy Meade and used by Mr E. J. Lovegrove, engineer and surveyor to the Hornsey District Council, in testing, for comparative toughness, practically all descriptions of road-stone in use; but of course tests of this kind are only of a comparative nature. This rotary machine, which is driven by a gas engine, consists of three cylinders, each 11½ inches in diameter, and in the inside of each, three 1 inch by 1 inch angle-iron ribs are riveted lengthwise. The sample of stones to be tested is subjected to what is known as the dry and wet process. The same weight of stones is used in each instance, namely, 4 lbs., and these are placed in the cylinders and subjected to 8000 revolutions at a speed of twenty revolutions per minute. In the wet test the stones are weighed dry and then placed in the cylinders, one-half gallon of water being added; the weight of the stones after testing is ascertained when they are thoroughly dry, and the loss recorded, from which the percentage in each case is calculated. The chips referred to in the statement, Table XIV., vary in size, the dust being in the form of a fine powder. In this test the stones should be a fair sample of the material used in actual practice, and in this particular they will vary considerably, according to whether they belong to an acid or basic variety of rock, and consequently of varying angularities approaching a cubical form. Any variation as to size, shape, and specific gravity will tend to produce diverse results, even with the same class of stones tested at different times. Such differences are in a measure unavoidable, while cleavage and porosity of the rock, a varying peculiarity even in the same quarry, affect the results in certain cases.

Experimental error will also, to some extent, be responsible for slight differences, while the selection of picked stones instead of a fair sample may be the cause of many of the apparently anomalous results. It is to the interest of many to obtain the best possible results for trade purposes, while others desire a test of the road-stones approximately as near as possible to their behaviour in practice, and presenting conditions which have to withstand the test of actual wear under traffic.

On the Continent and in America a machine for similar tests has been largely used, namely, Deval's impact machine. It consists of one or more drums which rotate about an eccentric axis. The stones to be tested are weighed previous to being placed in the machine, the cylinder being rotated at a speed of thirty revolutions per minute for five hours. The contents are then placed in a sieve having 0·16 cm. ($\frac{1}{16}$ inch) meshes, which separate the dust from the larger-sized material. The difference in weight of the latter and that originally placed in the machine represents the proportion of dust formed by abrasion. The best rocks produce, according to the French engineers, about 2 per cent. of dust, or 20 grammes per kilogramme of stone. The coefficient of wear is therefore represented by 20, from which the coefficent of other samples of rock can be determined by the formula: Coefficient of wear $= 20 \times \frac{20}{W}$ or $\frac{400}{W}$, in which W represents the weight in grammes of detritus under 0·16 cm. in size obtained per kilogramme (2·2 lbs.).

Impact and Drop Test.—The French engineers also test the ability of a stone to resist impact by means of an instrument closely resembling in principle a pile-driver. The test is made on 4 cm. cubes, which are fixed in the lower part of the machine, by a hammer falling on the specimen of stone. Two hammers are generally employed, weighing 42 and 20 kilogrammes respectively. These are raised by cords passing over pulleys, and can be released at any desired height, from which they fall upon the specimen under test. The number of blows necessary to crack the stone, and also the number required to produce complete destruction, are thus determined. The drop test used in this country by M. T. Clark is carried out by subjecting the specimen of stone to repeated blows from a falling weight. The hardness of a specimen of stone is ascertained by the usual mineralogical test. The tenacity of the stone by this method is proved by the resistance of the material to a hammer weighing 15 lbs. falling from a distance of 10 inches on the specimen, which is placed on an anvil. The samples of rock to be tested weigh 3 lbs., broken to road-metal, and capable of passing through, in all dimensions, a 2½-inch ring. The road-stone thus prepared is, by the repeated action of the weight falling, reduced sufficiently small to pass through a sieve of ¼-inch mesh, which size is taken to represent exhausted road-metal. The number of blows necessary to accomplish this is registered automatically. This method of testing has not, apparently, been much employed, although the principle would appear to be of some service in carrying out physical tests on road-stones.

Absorptive Power.—The absorptive power of a road-stone depends on its porosity; its utility being shown by the fact that the expansive influence of frost renders porous stones liable to disintegration. This test, like most others, is of a comparative nature, and the results probably vary to a greater extent than in any of the other physical tests. The absorptive power of road-stones varies considerably, the igneous rocks being the least absorbent. Limestones, on the other hand, show a high percentage of imbibed moisture, as is indicated in the following table.

TABLE XII.[*]

Granites absorb from	·1	to	·8	per cent.	of their	weight.
Basalts average about	·3			,,	,,	,,
Sandstones vary from	2·7	,,	8·5	,,	,,	,,
Limestones ,,	4	,,	12	,,	,,	,,

The first two rocks are, presumably, the best of their respective types. In experiments carried out by Mr Charles C. Moore[†] some granites were found to possess a porosity of from 4·68 to 19·90 per cent., the latter, however, indicating a decomposed state; while the porosity of andesite was 0·78, syenite (Mountsorrel) 0·32, and basalt (top of whinsill, High Cup Neck) 2·66 per cent. Road-stones characterized by closeness of grain, absence of cleavage, or planes of weakness and of decomposition-products generally, give the best results in this respect. They are therefore more chemically durable, and withstand the weathering effects better than more porous materials. The greater the absorptive power the more readily will the road-stone be reduced to mud under traffic in wet weather.

Crushing Test.—The compressive strength is determined by means of a hydraulic press, which indicates the resistance of a sample of carefully dressed cubes of stone to crushing. The results obtained by this physical test are, so to speak, of a positive nature; yet they may be very misleading in so far as the selection of a suitable stone for road-metal is concerned. Too much importance is generally attached to this property, especially by quarry-owners.

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[*] Vide *Roads*, Builder Student Series. Greenwell and Elsden.

[†] Vide *Quarry*, May 1903.

To show how delusive it is to attach undue weight to a high resistance to crushing, solely on account of a stone possessing this property, the following different kinds of stone may be compared. A specimen of rock from the Clee Hill quarries mentioned at p. 115, which is described as a tough, hard, fine-grained basalt, and "almost perfect as a road-stone," is capable of sustaining a crushing test of only 6 tons per square inch. Guernsey granite (syenite), also an excellent stone, and much used in London and the southern towns of England for road repairs, shows a crushing resistance of 12·75 tons per square inch.

Flints, on the other hand, are a very satisfactory material where the traffic is moderate, and are used to a considerable extent in many English counties where more suitable material cannot be obtained. This description of stone, however, cannot be compared with either of these preceding it for durability when subjected to the exigencies of traffic and weather; nevertheless, it has a high resistance to crushing, being slightly over 14 tons to the square inch. From this comparison it is evident that a high resistance is no indication of the wearing qualities of a road-stone under the practical test of traffic.

Samples of rock from the same quarry tested by this means often give results varying considerably, an average of these tests being taken as representing the crushing strength. In the preparation of the cubes, generally 6 inches, cracks and the probable inherent flaws in the sample, combined with their manipulation in the hydraulic press, give, on the small cubes tested, a different value than would be expected on blocks of larger size.

A stone having a high resistance to crushing clearly shows that other qualities are necessary in order that it may be sucessfully used for metalling purposes. It has been indicated that toughness alone is not the only quality requisite for a good stone, while one having a high resistance to crushing is equally deficient; so that of these two properties it is apparent that the one is quite as essential as the other for a stone to possess in order that it may be considered as having good wearing qualities.

Weathering Test.—This test, never of much utility, has been practically abandoned in connection with testing road-stones. The process of soaking a stone in a saturated solution of sulphate of soda (Glauber's salt), or the more practical method of artificially freezing the sample after prolonged soaking in water, is of no value. Any stone sufficiently porous to be disintegrated by these means is evidently quite unsuitable for use as road material.

Cementation Test.—The binding power of the detritus or dust formed from the abrasion of the different road-stones used, apart from the composition, aggregation of the minerals, and texture of the rock itself, has of late interested road engineers, and by many it is considered of such importance as to be a predominating factor in road maintenance. This can only obtain to any great extent in countries where the climatic conditions render such a quality absolutely necessary owing to long-continued drought. It should be borne in mind that wearing capacity is greater than cementitious power in roads of medium to heavy traffic.

In rolling operations a suitable binding material, depending on the nature of the rock from which the road-stones are prepared, fulfils the object in view, namely, aiding, in conjunction with judicious watering, the consolidation of the metal coating. Road-stone obtained from the more acid varieties of rock, particularly those of volcanic origin as distinguished from granites, can be treated with chips and dust obtained from the basic varieties of stone; that is, employing the cementitious dust binding material with these descriptions of road-metal, and *vice versâ*. This is not, however, practicable in most instances; therefore the application of suitable binding material, containing metallic oxides, which fulfil the necessary requirements, is generally employed. When at all possible, the author's invariable practice has been to apply loamy sand as a binding material with road-stones of a highly-silicated composition, and clean sand for the more basic varieties of rock, such as certain andesites and dolerites, and finishing with screenings from the stone-breaker in each case. Road-stone prepared from rocks of the latter description, or dolerite group, containing decomposition-products in most instances, would, if consolidated with dust and chips obtained during the breaking operations, be such as to make a road so constructed a disintegrated mass during alternating frost and thaw after a fall of rain. Roads coated and consolidated under these conditions produce, under traffic, a great quantity of mud in wet and dust in dry weather.

The abrasion of the stones in the crust of a road during extreme weather conditions creates detritus and adds to the amount of cementitious matter, but in certain varieties of rock the quantity thus produced is excessive, and creates much mud and dust.

Effective rolling, or the proper consolidation of a road-stone coating, extraneous binding being squeezed out and removed, is more effective in producing cementitious properties in the binding than that likely to be expected from dust and chips combined with water, giving the desired result by a possible chemical action, or disintegration of the particles.

The cementation test is considered in America as of great importance in determining the respective qualities of road-stone in the making and repairing of roads. The tests instituted there consist of intermixing with water the dust created by the attrition of road-stone tested for abrasion, forming a paste moulded in a short cylinder and compressed to 1422 lbs. per square inch. Two weeks are generally allowed for the briquette thus formed to dry, after which it is tested. A hammer weighing about 2 lbs. is allowed to fall upon it at intervals from variable heights, the standard being 0·39 inch; the blow being repeated until the binding capacity or cementation power of the material is destroyed. The number of blows is taken as representing the binding power of the stone.

The result of these tests * appears to show that road-stones containing decomposed mineral constituents are high in cementitious power, but rocks of practically the same variety give widely divergent values. Thus felsite tested by the Massachusetts Highway Commission, 1896–1901, gives a mean 'cementing value' of 42·6, while the Report of the United States Department of Agriculture in the Road-material Laboratory, 1900–1901, values the cementitious quality of this stone at 12 per cent. For other road-stones, such as gabbro, the values are fixed at 12 and 131, granite 8·8 and 23·4, limestone 16·0 and 85·4, sandstone 13·2 and 84·7 respectively, and the latter testing authority places the cementing value of clay at 2295·5.

Generally it must be inferred from these tests that the mud- and dust-producing materials are favoured because of their superior binding properties. The object in this country has been, and especially at the present time is, to avoid road-stones having such characteristic proclivities.

Microscopic Examination.—In considering the value of the physical tests mentioned it is apparent that information of a more reliable nature is desirable, and this can be supplied by the science of petrology. It is only in recent years that road engineers have availed themselves of this means of arriving at a definite conclusion as to the merits of different rock-types for paving-setts and road-stones.

The microscopic examination of the constituent minerals, texture, mode of crystallization of the rocks, and the chemical stability and decomposition-products of these minerals, are of the utmost assistance, and when combined with observations of their wear and behaviour in actual use, it surpasses any other method of determining the value of such materials under different conditions of locality and traffic.

The attrition test brings out many peculiarities of an interesting nature. In many instances the wearing capacity of the stone in actual use corresponds in a remarkable degree to the results obtained by this test as well as by the microscopic examination. In other specimens of stone, for reasons not easily explained, the results are widely divergent.

125. The petrological examination of a few typical rocks for road-making purposes will now be described briefly, accompanied with photo-micrographs of the stones, giving details of the constituent minerals, structure, texture, alteration, and decomposition-products and other characteristic features or peculiarities. Nos. 7, 10–14, and 16–18 inclusive refer to road-stones used by the author for many years past, while, in addition to the points mentioned above, the wear or behaviour of those in actual use will be given in detail, from which a general comparison may be made.

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* *Roads and Pavements*, Prof. I. O. Baker, J. Wiley & Son, New York.

TABLE XIII.

Some Typical Road-stones.

Nos. of Road-stones.	Reference Number.	Name of Quarry, etc.	Counties, etc.	Petrological Description of Stones.
1[1]	41[2]	Mountsorrel, ...	Leicestershire.	Biotite - hornblende granite.
2	108	Bordeaux Quarry, St Sampson's,	Guernsey.	Hornblende gneiss.
3	18	Vale Quarries, ,,	,,	Hornblendic gabbro.
4	117	Balmedie, Belhelvie, . .	Aberdeenshire.	Flaser hypersthene gabbro.
5	43	Threlkeld, ...	Cumberland.	Granite porphyry.
6	5	Narborough, ...	Leicestershire.	Quartz porphyrite.
7	55	Lindifferon, Cupar, . . .	Fifeshire.	Felsite.
8	119	Groby, ...	Leicestershire.	Granophyre.
9	57	Darbishire's Quarries, Penmaenmawr,	Carnarvon.	Quartz enstatite diabase.
10	91	Dunmimonkshill, Strathmiglo, .	Fifeshire.	Andesite (acid).
11	209	Bridgend, Auchtermuchty, .	,,	,, ,,
12	54	Mount, Cupar, ...	,,	,, ,,
13	50	Foodie, ,, ...	,,	,, (basic).
14	90	Kinnear, St Fort, . . .	,,	Olivine basalt.
15	3	Titterstone Quarries, Clee Hill, Ludlow,	Shropshire.	,, dolerite.
16	163	Baldinnie, Ceres, . . .	Fifeshire.	,, ,,
17	93	Broomknowe, Craigrothie, .	,,	Ophitic ,,
18	...	Monimail, Collessie, . . .	,,	Dolerite.
19	16	Cherbourg, ...	France.	Quartzite.

[1] The numerals 1, 2, 3, etc., refer to paragraphs and figures in text.

[2] These figures refer to the attrition tests carried out by Mr E. J. Lovegrove.

In the following description the figures refer to the road-stone in the preceding table and the photo-micrographs in Plate III.

1. *Mountsorrel.**—This is a fine-grained dull-red stone. On a newly-

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* The petrological descriptions of Nos. 1, 2, 3, 4, 5, 6, 8, 9, 14, and 17 are taken from the *Surveyor*, 10th Nov. to 28th Dec. 1905 inclusive, and the author is indebted to the editor of that paper for the photo-micrographs referred to above, and shown in Plate III. The author is also indebted to Professor Joly, Dublin University, and the proprietors of the *Quarry*, for undertaking microscopical examinations of numerous road-stones. The results of these have been published, and some are included in the typical road-stones

fractured surface it is easy to make out the dull-red felspar, the green chlorite and dark grains of hornblende, and clear shining quartz can be seen between the other mineral grains. The felspar is decomposed and stained red. It occurs partly in small porphyritic crystals, fig. 1 B–C3, and partly in much smaller crystals, forming a ground-mass with quartz. The dark minerals are biotite (weathered to green chlorite), C–D4, and greenish-brown hornblende, A–B, 1–2. A good deal of the felspar is plagioclase. The quartz is all in the ground-mass, and is the last ingredient to crystallize, as it encloses the latest felspars.

The texture and structural features in which the late crystallization of the quartz or the production of secondary quartz in a kind of ground-mass, together with the small amount of alteration and decomposition-products, causing a reduction in size of the component grains, all go to make a hard and resistant material. This rock is much used for road-making purposes in many counties in England.

2. *Guernsey 'Blue Granite.'*—This is a dark bluish-green stone of medium grain and crystalline texture; the white grains of felspar and quartz, and the green ones of hornblende, are easily distinguished by the unaided eye. It consists of green hornblende in irregularly-shaped masses, a little weathered biotite, orthoclase and plagioclase felspar, and quartz. The structure is gneissose, but approaches granitic in some parts of the slide. Effects of crushing are seen, especially in the quartz. The iron-ores may be surrounded with granular sphene. The only constituents which show idiomorphism are the felspars, occasionally, and the apatite.

The predominance of hornblende is noticeable in fig. 2, where all the grey-shaded portions represent this mineral, A–D5. The paler portions are either felspar, D2, B4, or an aggregate of quartz and felspar-grains, A1–4. This stone is also much used in the southern counties as a road-making material.

3. *Guernsey Hornblendic Gabbro.*—The structure of this rock is that of the gabbros rather than that of the diorites. The section fig. 3 shows that the rock consists principally of plagioclase felspar in short, rounded individuals, and of clear pale-brown augite in crystals, which are sometimes, though not usually, idiomorphic. The felspar and pyroxene are both schillerized in places, and the augite has not unfrequently the platy structure of diallage. No olivine is present, but there are many large crystals of hornblende, dark green in colour, enclosing plagioclase felspars in an ophitic manner. This hornblende may be intergrown with the diallage, either in scattered patches or as a border on its surfaces. Iron-ores and apatite are also present, and there are a few bastite pseudomorphs, apparently after idiomorphic enstatite.

described in these pages. *Vide* also *Scientific Proceedings of the Royal Dublin Society*, vol. x. (N.S.) part iii. No. 30, published 13th May 1905 (from which figs. 16 and 17 have been reproduced by permission of the Society); and *Quarry* of May and June 1905.

The large dark masses in the lower part of fig. 3 belong to a crystal of green hornblende; the white bodies enclosed in it are crystals of felspar. The dark-grey cross-hatched mineral in B–D5 is also hornblende; the paler grey material seen in the figure is augite; the black bodies in A–B1 and in B3 are iron-ores. All the clear parts are felspar.

4. *Balmedie Hypersthene Gabbro.*—A dark-grey stone with a well-marked shininess on the freshly-fractured surface. The main components of this rock are diallage, hypersthene, and plagioclase felspar. The diallage is brownish, and, in addition to the usual prismatic cleavages, has the platy structure characteristic of this mineral; the hypersthene has a distinct pleochroism, ranging from pink to clear green; the plagioclase is schillerized and filled with small opaque enclosures. The rock contains a little biotite and iron oxides altered to acicular actinolite and sphene. The large plates of diallage are curved and distorted, and the felspar begins to assume the character of granulitic mosaic. Chlorite and bastite, as decomposition-products, are somewhat abundant. The whole of fig. 4 is occupied by grains of felspar, except under A–B–C5, where the extremity of a large plate of diallage is seen.

This rock would appear to make a good road-stone, notwithstanding the prevalence of chlorite, etc., and is intended to supersede certain of the granites, especially coarse-grained types, which have hitherto been used in most parts of Aberdeenshire, but which produce much mud in wet and dust in dry weather.

5. *Threlkeld Granite Porphyry.*—In this rock large crystals of quartz and of felspar lie scattered through a matrix of smaller grains of the same minerals. All the felspar is turbid and semi-opaque, through weathering. There have also been large and small biotite crystals, but these have been altered to chlorite. Secondary muscovite has formed through the rock, as a product of the decomposition of the original felspar.

The relative size of the quartz crystals and the ground-mass is clearly seen in fig. 5; neither the muscovite nor the large porphyritic felspar is included in the view. The grey portion of the ground-mass is felspar; the clear white is quartz. A number of small flakes of chloritized biotite may be observed about the centre of the figure.

6. *Narborough Quartz Porphyrite.*—This rock consists of more or less decomposed plagioclase crystals, corroded quartz grains, green decomposition-products after the ferro-magnesian minerals, magnetite or ilmenite, and a micro-crystalline mosaic of quartz and turbid felspar, which constitutes the ground-mass. The porphyritic felspar appears to be wholly plagioclase.

In the hand specimen it is pink or light red, and shows well the small porphyritic felspars and green spots of chlorite and other secondary minerals.

Portions of larger felspar crystals lying in a matrix of micro-granitic felspar and quartz are shown in fig. 6; the felspar of the ground-mass appears dark, through it being very turbid and stained red.

The decomposition-products of this rock, although pronounced, would appear not to affect it greatly; the structural arrangement of the component minerals is characteristic, which no doubt tends in this stone to durability.

7. *Lindifferon Felsite.** Geological formation $\mathrm{Po}^{\mathrm{Cl}}$.†—This rock is very fine-grained, and of a terra-cotta colour and dull lustre. It consists of a crypto-crystalline felsitic ground-mass with small angular crystals of quartz evenly distributed throughout. Frequent felspars occur, short and stout, and some elongated, and form a closely-interwoven mass. These felspars are idiomorphic, and often show turbid cavities; they polarize in grey tints, and many are probably orthoclase, the structure in some cases resembling hour-glass form. The felspars are only distinguishable, without polarized light, by their slightly deeper brownish colour, and there is occasionally some indication of flow or banded arrangement. Biotite is present in small flakes varying in colour from pale yellowish to greenish-brown; they are often found bent, and at times associated with ragged masses of red-brown oxide of iron; traces of hypersthene and augite are found. These masses range from dimensions similar to those of the felspars to minutest particles, and confer upon the rock its red colour.‡

After five years' use on a road the stones were not found to be much rounded, but the surfaces were somewhat smooth.

The stone is very hard, but deficient in toughness. It has been successfully used in damp and shaded places where the material formerly in use and of fairly good quality was worn down quickly and produced much mud in wet weather. The stone, however, spalls in dry exposed situations, while in damp places the moisture appears to stimulate toughness. One peculiarity observable in connection with this road-stone, not existing in any other, in the author's experience, is that no mud is created through wear in wet weather, the resultant detritus being fine sand which possesses good binding qualities.

8. *Groby Granophyre.*—The red patches in a hand specimen of this rock are a fine undergrowth of quartz and felspar (micro-pegmatite), in which the other ingredients are embedded. The green streaks are chlorite, iron-ores and epidote, derived from some ferro-magnesian mineral which can no longer be recognized. Larger well-shaped porphyritic crystals of felspar lie scattered through the rock, and are visible in thin slices; they include both orthoclase and plagioclase, but are often much weathered. Quartz

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* This rock occurs in dykes, not shown in the geological maps, and can be traced from near Fliskmiln on the river Tay over Norman's Law, cutting through dolerite dyke there, and on to Lindifferon and Rankeillor, near Springfield. Dykes and veins can be traced eastwards of Fliskmiln to Luthrie.

† The nomenclature is that given on the Geological Survey sheets 40, 41, 48, and 49.

‡ This road-stone is described as a hypersthene andesite in *Quarry*, May 1905, p. 204

very rarely forms definite areas of any size, occurring almost solely in small angular patches in the felspar of the ground-mass.

All the upper part of the photo-micrograph fig. 8 is occupied by the intimate graphic intergrowth of felspar and quartz; the individual elements are finer above and become coarser below. The dark masses B4 and D4 are alteration-products of the felspar; the black masses D1 and E5 are green ferro-magnesian minerals. The grey rectangular crystal in E1 is one of the porphyritic felspars.

9. *Quartz Enstatite Diabase.*—This stone, of compact grey, and breaking with a clear cuboidal fracture, a variety of the Penmaenmawr enstatite diabase, is fine-grained, and consists mostly of small crystals of quartz and felspar. The quartz is clear and transparent; the felspars are cloudy and dull through weathering. Pseudomorphs of bastite, after enstatite or bronzite, occur in plenty, and have a well-marked crystalline form. There is also some granular brownish augite, ilmenite weathering to leucoxene, and apatite. Even in the hand specimen the porphyritic structure is distinct, and is due to the presence of large phenocrysts of felspar and of enstatite. The photo-micrograph resembles fig. 9, but shows a finer grain. The clear parts in the figure are quartz, the grey parts felspar, in the upper left corner; while in the opposite corner the grey portion represents enstatite and the white part felspar, D1. The black masses are ilmenite.

This rock is largely used as a road-stone, and gives great satisfaction.

10. *Andesite* (acid). Geological formation Pc^1.—This rock is described as a banded, fluidal, dark-brown andesite, and consists entirely of small lath-shaped crystals of felspar, arranged with their long axes more or less parallel. There is no augite or other ferro-magnesian mineral, but much magnetite and hematite in small grains and irregular stains; these give the rock its dark-red tint. The felspar is mostly plagioclase, but there seems to be a fair proportion of orthoclase mingled with it.

It is a hard and fairly tough road-stone, is recognized as durable, and has given satisfactory results in every particular. There being no decomposition-products present in this rock, the road-stones produce little mud or dust. The toughness is probably produced by the manner in which the magnetite and hematite, although in large quantities, are distributed. Stones removed from the road after many years' wear are neither much rounded nor smooth.

11. *Andesite* (acid). Geological formation Pc^1.—This rock is very fine-grained, and of a colour varying from brownish-grey to black. The ground-mass is holocrystalline and contains lath-shaped and some square felspars with fluxion structure. The augite is somewhat altered; the phenocrysts of felspar are fresh and clear, and hematite and magnetite are common in grains, dust, and crystals.

It breaks under the hammer with a sharp conchoidal fracture, and yields only, however, with difficulty to the hand lever. After two and a half years' wear the stones are rounded and smoothed.

The stone gives excellent results, is very durable in all situations and under all conditions of traffic, and comparatively little mud is formed in wet weather.

12. *Andesite* (acid). Geological formation Po^{C1}.—The colour of this rock varies from dark grey to nearly black; it is a porphyritic andesite with large crystals of plagioclase felspar in a crystalline felspathic ground-mass and fluxional structure. The large felspars have well-defined crystalline forms, clear and fresh, and with some traces of what appears to be bastite or hypersthene. Augite is scarce, clear to colourless, and there is a fair amount of magnetite in dust and small crystals, as also some red oxide of iron, chlorite, and calcite. Fig. 12 shows a group of large porphyritic plagioclase crystals lying in the ground-mass of the smaller crystals; the flow structure is well defined in this photo-micrograph. Under the hammer the stone breaks fairly easily, showing no cleavage.

This road-stone has been extensively used and found satisfactory in regard to durability on roads carrying heavy traffic, and its behaviour is generally good under all weather conditions.

Specimens of stones taken up after four years' wear are much rounded and the surfaces smoothed.

There is, however, a structural peculiarity in the rock, in certain parts of the quarry, which causes it to change its position in the working face from time to time as operations are extended.

The micro-photograph fig. 12 has been selected, among others, to show this peculiarity, which is also met with in many volcanic rocks in a greater or less degree, and is known as flow or fluxion structure.

The peculiarity referred to is at times pronounced, and the author, while regarding the material generally as of excellent quality, has experienced on the roads metalled from this quarry a condition of surface which could not be readily explained. Small depressions appeared and at certain points increased, which necessitated investigation as to the cause. The road was pitted at different places and carefully examined, but the bottoming was found to be in good condition. The road-stone itself, in these depressions, was then examined, and it was discovered, in most instances, that the stones were of a flaky nature, and could be separated easily in thin layers, evidently pointing to the fact that the cohesion between the component minerals had been destroyed. The cause, therefore, was not difficult to trace, more especially after a careful examination of the petrological characteristics of this and other road-stones.

The structural peculiarity is, in this instance, very marked, and the defects previously experienced with this road-stone in the proper maintenance of the roads has been obviated by rejecting, as far as possible, the affected portions of rock during quarrying operations and when breaking the material.

13. *Andesite* (basic). Geological formation Po^{Cl}. — This is a fine-grained black rock. The ground-mass is holocrystalline, and is composed of lath-shaped and irregular-sized felspars, with some flow structure. The phenocrysts are felspars, lamellar and simple twins, but are not plentiful. A faintly pleochroic enstatite or hypersthene exists, colourless to pale pinkish in appearance. Biotite, pleochroic, associated with red oxide of iron and epidote, are also present, and some chlorite. Small grains of augite are associated with an olive-green alteration-product. The fracture is only feebly glistening or nearly dull. The rock is fairly tough, although it breaks easily under the hammer, the fracture being more or less conchoidal. It also shows some cleavage.

After four years' wear the stones are fairly rounded and the surfaces smooth.

As a road-stone it is very durable, and wears uniformly under traffic, the portions of rock showing marked fluxional structure being used for quarry road repairs.

14. *Olivine Basalt.** Geological formation Po^{Cl}.—This rock has a fine grain, and is dark-grey to nearly black in colour, with inconspicuous reddish-brown spots. The ground-mass consists of a mixture of augite and very small lath-shaped felspars, apparently triclinic. There are very few phenocrysts; a few idiomorphic felspars with zonal structure, and with simple twinning or not twinned; rarely lamellar. A decomposed mineral, apparently olivine, is veined with hematite; there is also a little magnetite present. Spicules are also fairly abundant, green-brown to opaque, but no pleochroism or optical activity is visible in these.

Under the hammer this stone breaks fairly easily, and has little or no cleavage.

After nearly five years' wear in a road, the stones are considerably rounded and the surfaces smooth.

This olivine basalt produced fairly good road-stones when the quarry was newly opened; but the quality at present is not so satisfactory, caused apparently by a greater abundance of decomposed olivine as serpentine. The iron-stained olivine is represented by the black masses in fig. 14. This stone appears, even at the present time, to be of good quality; but in this particular, both an eye-examination and experience fail in detecting the nature and bulk of the decomposition-products, and this in great measure emphasizes the desirability of ascertaining the physical and petrological characteristics of road-stones in each instance. Road-stone No. 161, Table XIV., p. 121, has been substituted for this olivine basalt.

15. *Olivine Dolerite.*—This rock is a rather coarse-grained olivine diabase commonly known as 'Clee Hill Basalt.' In the hand specimen the green olivine, black augite, and dark-grey plagioclase felspar can easily

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* This rock has been described as a basic andesite and an olivine dolerite.

be made out with the help of a lens. Under the microscope the olivine appears as clusters of rounded grains weathering to serpentine. The augite is greyish-brown and, though sometimes forming groups of idiomorphic crystals, is for the most part in small grains of irregular form, moulded on the felspars, so that the structure is of the 'ophitic' type. The plagioclase felspar occurs in long lath-shaped crystals. Ilmenite is abundant in irregular plates, and there are many fine needles of apatite. As a rule, all the ingredients are very fresh and well preserved for rocks of this kind, though there are small patches of cloudy analcite and other zeolites filling angular spaces between the felspars.

The most prominent feature in fig. 15 is the olivine in the lower right-hand corner. In D2–3, E1, A1, and B1, augite is shown; the remaining clear portions are the lath-shaped felspars.

This is one of the best-known road-stones in this country, and is extensively used in many parts of England.

16. *Ophitic Olivine Dolerite.* Geological formation Gn Bd^2.—This rock is a typical ophitic olivine dolerite, and black in colour. The olivine is mostly altered to serpentine; the augite is abundant, ophitic, with lath-shaped felspars, and very fresh. It is rather coarse-grained, and breaks with a rough fracture, showing its crystallized constituents glistening like broken sugar. There is no cleavage, and it is very tough under the hammer. The felspar in fig. 16 is the lightest in colour, the darkest parts being iron-ores. The intermediate shade is the fresh augite in which the felspars are embedded. In the lower right-hand quadrant two crystals of altered olivine are seen.

A sample of stones taken from the road shows them to be considerably rounded, but with fairly rough surfaces. The removal of the angles, through wear, surface and internal, has not apparently destroyed the rough surfaces. There is no visible sign of chemical change.

This variety of dolerite is most durable, and wears well under all conditions of traffic and weather. Under traffic in wet weather it produces very little mud, and is considered an ideal road-stone.

The road-stone shown in fig. 16A is similar to the above, but has more decomposition-products. Like No. 16, the rock is a good example of the class to which it belongs, both as regards its structure and the character of its component minerals. It has been likened to the Clee Hill stone No. 15.

17. *Ophitic Dolerite.* Geological formation Gn Bd^1.—This rock is similar in appearance to Nos. 16 and 16A, but coarser-grained. The felspars are fresh, and in places ophitic towards an abundant augite. The latter mineral, however, is much altered to serpentine, and in every case veined with this decomposition-product. There is also a good deal of ilmenite or magnetite. In fig. 17 the augite is so much darkened by decomposition-products as to be hardly distinguishable in many places

from the opaque iron-ores. It is tough under the hammer, and gives a rough fracture. After some years in the road the stones are considerably rounded and the surfaces smooth.

The wearing qualities of this stone are far from satisfactory; the macadam produces large quantities of mud in wet and dust in dry weather. Except on hilly roads, it has been practically abandoned as a material for main roads, one of the andesite family being substituted.

18. *Dolerite.*[*] Geological formation B.Ts^{C1}.—This rock is of a dark-grey colour without olivine, or very little, with a fairly rough and glistening fracture, and finer in texture than No. 16. It is made up of felspars (fresh) of the usual type, embedded ophitically to some extent in a very much decomposed augite. This mineral, which amounts to about one-fifth of the bulk analysis, is changed for the greater part into a cloudy grey substance, in which is much chlorite. There is little magnetite or ilmenite present.

Like the preceding road-stone, this dolerite produces much mud in wet and dust in dry weather, and has been discarded entirely, owing to its inferior wearing qualities.

It is much used for kerbing, channels, etc., for which it is in great demand, and, considering the abundance of decomposition-products, gives satisfactory results.

19. *Quartzite.*—This is a compact grey stone, with slight yellow staining in the joints. Under the microscope the elastic or fragmental structure is clearly recognized; the round quartz grains, which are often 1 mm. in diameter, lying in a matrix of much smaller, angular, and rounded pieces. All the grains are firmly cemented together by siliceous materials, containing a little mica and chlorite. There is almost no felspar in the rock; the accessory minerals are zircon and iron-oxides, with a few specks of pyrites.

The quartz grains are mostly optically simple, and may have come from granitic rocks; a few are crushed, and may have been derived from gneisses or schists of the metamorphic group.

Fig. 19 is taken by ordinary light to show how these stones appear in thin slices without the polariscope, the two sizes of grain being clearly distinguishable.

126. A comparison of some of the road-stones contained in Table XIII. may be given in regard to their petrological characters, comparative toughness as ascertained by the attrition tests (Table XIV.), and some observations of the actual wear of these stones. There are many other excellent rocks suitable for road-stones occurring in various parts of the country, but, for obvious reasons, it is impossible to enumerate them here.

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[*] Dyke 40 to 60 feet wide, extending from Glenfarg, Perthshire, through Fife, passing near Auchtermuchty, Monimail, Letham, East Hall, Cupar, and terminating, to all appearance, east of Prestonhall farm steading, between Cupar and Dairsie.

Clee Hill rock (olivine dolerite) is recognized as one of the best road-stones in England, and this is borne out by the attrition test, although the texture is rather coarse-grained. The average loss per cent. of dust is 7·22. The ophitic structure and the comparatively small amount of decomposition-products appear to give this stone its resistant qualities.

Road-stones No. 16 and 16A (ophitic olivine dolerite) have been likened to Clee Hill stone. They are excellent wearing materials under all conditions of traffic and weather, and may be said to combine the qualities of hardness and toughness in a marked degree. They do not, however, come out well in the attrition tests, the average percentage of dust being 14·84, or nearly double that in the case of the Clee Hill stone. The percentage of dust in the wet test is abnormally high, and would, in some rocks at least, be accounted for by a large amount of decomposition-products in the stone; but with the road-stone in question (No. 16) there is only a small proportion of olivine altered to serpentine, while the ophitic structure is also in its favour. This road-stone produces very little mud in wet weather, and the roads are comparatively dustless during fine weather.

Road-stone No. 17 (ophitic dolerite) is composed of practically identical characters possessed by road-stone No. 16, which has a perfectly fresh and unaltered augite; but in the stone in question (No. 17) the augite is much decomposed, and the ophitic structure, an all-important feature in this group of rocks, is rendered useless, and the coherence or resisting properties of the stone are therefore lost. It produces much mud in wet and dust in dry weather. It is therefore not exceptional to find the dust percentage in the attrition test as high as 27·51. This stone, formerly extensively employed, is now only used on hilly portions of roads where the subsoil and surface drainage are good, it having been found a very unsatisfactory material on level stretches of roads.

Road-stone No. 7 (felsite) is a peculiar stone in many respects. It is hard, but of a brittle nature under certain conditions, and practically devoid of toughness. It shows a dust percentage in the attrition test of 5·22 only, being better than Clee Hill stone in this respect, and producing a third of the quantity of dust yielded by road-stone No. 16. The large amount of chips in this case indicates a brittle nature. It cannot be considered in any way equal to road-stone No. 16 in durability, although in damp or shady places it wears very well, dampness evidently promoting a certain degree of toughness, but it is not a reliable stone on exposed or on hilly roads. Probably its fine grain and low specific gravity have something to do with the small percentage of dust in this test. There is no mud produced from this stone, the detritus being a fine sand of fairly good cementitious properties.

Road-stone No. 10 (andesite, acid) is an excellent wearing material and of a durable nature. It is one of the best of the andesite group of rocks in Table XIII.; not so good, however, as No. 16, but more satisfactory than

road-stone No. 7. The attrition test shows its comparative toughness as represented by an average dust percentage of 8·03. This road-stone is capable of sustaining heavy traffic, and produces very little mud or dust.

Road-stones Nos. 11, 12, and 161 are good wearing, and generally make satisfactory macadam. There is, however, flow-structure in these rocks which has to be guarded against in winning the material, especially where it exists in a marked degree. The percentage of dust averages from 5·88 to 13·45, which is considerably larger than the previous road-stone, and more than double that of No. 7. All these andesites are superior to road-stone No. 7.

Road-stone No. 13 (andesite, basic) is a fairly good wearing stone, but produces more mud and dust than the preceding acid andesites. Flow-structure occurs in this rock also, and the augite is altered, which may account for its higher percentage of dust in the attrition test, namely, 15·68.

Road-stone No. 14 (olivine basalt *), formerly understood to be a basic andesite, has not of late proved to be of a durable nature. Much mud is produced, under traffic, in wet weather, and the surface of road wears into cups or depressions, producing an uneven surface, caused by irregular wear. Probably the alteration-products of olivine into serpentine, etc., are more pronounced than formerly, as the attrition test shows an average percentage of dust of 13·60. This material has been superseded; road-stone No. 161 being used instead with satisfactory results. The amount of dust by attrition test shows, in the latter, an average of 12·57.

Road-stone No. 19 (quartzite) shows a large proportion of chips in the attrition test, and is probably a brittle stone, although the comparative toughness stands high, the average percentage of dust being 5·71.

127. Generally the attrition tests agree, to a certain extent, with the practical experience of these stones, although there are anomalous results which cannot be very well explained. Beyond doubt road-stone No. 16 is by far the best, and similar rocks having fresh minerals or but slightly decomposed products. The andesites come next, but are somewhat variable in durability, and fluxion-phenomena may account for this, to a certain extent; then follow the felsites (No. 7). Dolerites, of which No. 17 is an example (there are many quarries producing this class of rock), are not to be recommended, as actual experience shows that the amount of decomposition-products present detracts from their durability, while their mud- and dust-producing proclivities, as may be imagined, are pronounced.

It may be mentioned here that the latter description of road-stone was much used in East Fife many years ago, previous to the introduction of steam-rollers. The material was rather difficult to quarry and costly to

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* "Attrition Tests of Road-making Stones," vide *Surveyor*, 10th Nov. 1905.

TABLE OF ATTRITION TESTS, No. XIV.

No. of Road-stones.	Reference Number.	Description of Stone.	Quarry or Locality.	Hand (H) or Machine (M) Broken.	Chips.		Dust.			Specific Gravity.
					Percentage Detached from Parent Stone.		Percentage of Loss.			
					Dry Test.	Wet Test.	Dry Test.	Wet Test.	Average.	
1[1]	41[2]	Biotite-hornblende granite,	Mountsorrel, Leicestershire, ...	M	1·46	2·98	5·47	7·76	6·61	2·73
	77	Porphyritic granite, . .	Shap Granite Quarries, Westmorland, . .	M	0·53	0·39	12·94	17·53	15·23	2·65
	103	Muscovite-biotite granite, .	Rubislaw, Aberdeen, ...	H	·0	·0	8·39	12·99	10·69	2·70
2	108	Hornblende gneiss (2 m.), .	Bordeaux Quarry, St Sampson's, Guernsey, .	...	1·76	·05	6·15	9·91	8·03	2·86
3	18	Hornblendic gabbro, . .	St Sampson's and the Vale Quarries, Guernsey,	...	·0	1·37	9·18	12·30	10·74	2·99
4	117	Flaser hypersthene gabbro,	Rocks of Balmedie, Belhelvie, Aberdeenshire, .	H	1·02	·34	7·66	10·50	9·08	2·81
5	43	Granite porphyry, . .	Threlkeld, Cumberland, ...	M	·0	0·19	6·01	8·98	7·49	2·67
	14	Quartz porphyrite, . .	Quenast, Belgium, ...	M	·0	·0	2·93	4·54	3·73	2·76
6	5	,, ,, . .	Narborough, Leicestershire, ...	H	·05	·0	4·10	5·47	4·78	2·64
7	55	Felsite, ...	Lindifferon Quarry, Cupar, Fifeshire, . .	H	5·12	·78	5·22	5·22	5·22	2·49
	115	Granophyre, . . .	Gask Quarry, Skene, Aberdeenshire, . .	H	·83	·14	4·24	5·42	4·83	2·58
8	119	,, . . .	Groby, Leicestershire, ...	...	·39	1·96	6·45	12·50	9·47	2·76
9	57	Quartz enstatite diabase, .	Darbishire's Quarries, Penmaenmawr, . .	...	·0	·0	3·91	7·03	5·47	2·75
	127	Diabase, ...	Hill Top Quarry, Dunsford, South Devon, .	H	·15	·15	5·13	6·69	5·91	2·87
	76	,, ...	Central Wales Granite Company's Quarries, Llandrindod, Radnorshire, ...	H	1·12	1·02	9·37	16·94	13·15	2·68
	44	Uralitic diabase, . .	Meenaweary Quarry, Buncrana, Co. Donegal, .	H	·0	·0	3·51	5·91	4·71	3·09
	46	Epidiorite, . . .	Ardlough Quarry, near Londonderry, . .	H	2·10	·59	18·80	41·06	29·93	2·76
10	91	Andesite (acid), . . .	Dunnimonkshill, Strathmiglo, Fifeshire, . .	H	·34	·0	5·76	10·30	8·03	2·70

11	209	Andesite (acid), . . .	Bridgend, Auchtermuchty, Fifeshire, . .	H	·0	2·49	4·40	7·87	5·88	2·64
11	210	,, ,, ...	,, ,, ,, . .	M	·78	0·39	5·66	9·72	7·69	
12	54	,, ,, ...	Mount Quarry, Cupar, ,, . .	H	2·44	·97	8·44	12·99	10·71	2·67
	161	,, ,, ...	Forret ,, ,, ,, . .	H	4·30	·0	9·18	17·72	13·45	2·65
	162	,, ,, ...	,, ,, ,, ,, . .	M	·83	·0	9·72	15·43	12·57	2·76
13	50	,, (basic), . .	Foodie ,, ,, ,, . .	H	3·66	3·17	9·58	21·78	15·68	2·73
13	51	,, ,, ...	,, ,, ,, ,, . .	M	2·50	2·54	10·15	22·75	16·45	2·73
14	90	Olivine basalt, . . .	Kinnear Quarry, St Fort, ,, . .	M	1·90	1·61	8·45	18·75	13·60	2·80
15	3	,, dolerite, . .	Titterstone Quarries, Clee Hill, Ludlow, Shropshire, ...	H	·0	·0	6·00	8·45	7·22	2·91
16	163	,, ,, . . .	Percy Baldennie Quarry, Ceres, Fifeshire, .	H	·0	·0	10·74	24·85	17·80	2·94
	164	,, ,, . . .	,, ,, ,, ,, . .	M	·0	·0	12·69	24·32	18·50	2·86
16A	52	,, ,, . . .	Newbigging ,, ,, ,, . .	H	3·32	·19	10·05	19·63	14·84	2·97
	53	,, ,, . . .	,, ,, ,, ,, . .	M	·0	·0	11·96	21·38	16·67	3·01
17	160	Ophitic, ,, . .	Broomknowe Quarry, Cupar, ,, . .	H	·0	1·32	15·43	39·60	27·51	2·77
	93	,, ,, . . .	,, ,, ,, ,, . .	M	1·12	1·17	11·03	42·09	26·56	2·85
	11	Quartzite, ...	Hartshill, near Atherstone, Warwickshire, .	H	·0	·29	6·25	8·35	7·30	2·65
19	16	,, ...	Cherbourg, France, ...	H	2·78	·19	5·47	5·95	5·71	2·68
	125	Greywacke, . . .	Glynrhonwy Slate Quarry, Llanberis, Carnarvonshire, ...	...	·29	·0	10·06	19·82	14·94	2·70
	111	Felspathic sandstone, .	Gorse's Quarry, Bury, Lancashire, . . .	H	1·22	1·03	36·86	53·12	44·99	2·63
	37	Dolomite limestone, . .	Churston Quarry, Torquay, Devonshire, . .	...	5·52	2·00	14·79	29·05	21·92	2·74
	32	Crystalline limestone, .	Walls Hill Quarry, ,, ,, . .	..	3·61	7·03	18·36	34·22	26·29	2·71
	35	Limestone, ...	Barton, St Mary's Church, ,, . .	H	1·85	3·95	17·53	30·71	24·12	2·71
	21	Pit flints, ...	Longfield, Kent, ...	H	2·34	5·86	9·03	7·37	8·20	2·63
	65	Picked surface flints, . .	Farnborough, Berkshire, ...	H	5·91	3·27	10·98	12·30	11·64	2·76

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[1] These figures refer to the different road-stones described in text.

[2] These figures are the reference numbers of the attrition tests carried out by Mr Lovegrove, and published from time to time, most of which appeared in the *Surveyor* of 10th November 1905.

break into macadam; the only good property, if it could be so considered, was that under wheel traffic the patches of stone set quickly in the road and required little attention during the process of being amalgamated with the old surface. Needless to say, this description of rock is now used only to a limited extent, and that principally on hilly roads contiguous to the respective quarries. The andesites and such rocks as that described under No. 16, although the cost for haulage is greater, are now extensively employed, with beneficial results. This clearly proves that ultimate gain, both in efficiency and economy, is secured by using a better class of stone. The diminution of mud and dust is very marked, which alone deserves consideration.

Attrition tests of other road-stones are given in Table XIV. for comparison.

128. From the description of the different types of rock for road-making purposes, and a study of the typical road-stones mentioned in the preceding pages, it is evident that, without a petrological examination of the rock, the selection of suitable material is a rather complex problem. The choice in many cases, however, frequently lies between an inferior and cheaper stone close at hand and a better but more costly one brought from a distance. Local considerations, therefore, enter into the question, and the relative quality of the available rocks proves, in most instances, that the better and more expensive material is, ultimately, the more economical. In this particular, road engineers are becoming more alive to the absolute necessity of using only the best possible road-stones, taken with a consideration of the varying conditions involved, at the present time, in road maintenance.

The nomenclature given by many quarry-masters to their particular stone should be guarded against as very misleading, many rocks, such as basalt, dolerite, etc., having been sold as granite, probably under the mistaken idea, at least for macadamizing purposes, that it was supposed formerly to be one of the best materials for road-making.

129. **Mineralogical Composition.**—The microscopical examination of road-stones can alone reveal, in a positive manner, the component minerals, the structural peculiarities, and mutual relations of the constituents. These petrological examinations do not merely involve an investigation into the composition of the rock, but, in a manner, its history, as in the crystallization of the minerals, intergrowths, decomposition-products, fluxion phenomena, effects of fracture, or the rock structure generally, and the chemical stability of the constituent particles. The relative abundance of the essential and accessory minerals, and the manner of consolidation of the molten magmas, especially in the volcanic group of rocks, differ materially in character. The difference in coarseness and fineness of texture is caused by the peculiarities in the mutual arrangement of the constituent minerals under the diverse conditions of consolidation.

130. The rounded condition of some of the road-stones examined and mentioned in the preceding pages, irrespective of the group of rocks to which they belong, is not wholly caused by legitimate wear. The expansion of water in freezing often does damage to the crust of a road, and affects the material considerably. Experience shows, however, that macadam of a hard and practically non-absorbent nature, compared with those road-stones which contain a large proportion of decomposition-products, is not so much affected; consequently far less damage is caused. Nevertheless, and apart from a certain amount of wearing of the angles during extremes of weather, or internal abrasion, alternating frost and thaw, experienced in many counties in Scotland during the winter months, and especially during the month of February, cause great damage, and also permit the wheels of vehicles to lick up the stones, thus causing disintegration. It is not an uncommon experience in these counties to have showers of rain succeeded by frost during the night and a thaw during the following day. At this time of the year the actinic power of the sun's rays is such that the frozen surface is thawed, and the action of wheel traffic causes the stones to be lifted out of position and scattered about. These climatic peculiarities often continue for weeks together—a trying ordeal even with roads made of the best material. Only the highest grade road-stone that can be procured is used on the main roads, and is consolidated with binding of a sandy nature; but even roads coated with such stones suffer, through this cause, comparatively great damage at times.

On roads over which heavy traffic passes, experience proves that by using the best material for repairs, although it costs more than a local stone of inferior quality, the ultimate expenditure will, taking all the varying conditions into consideration, be considerably less per annum. On roads which are not subjected to heavy traffic, metalling of a less durable nature, such as flints, hard limestone of a crystalline appearance, and millstone grit, may, under certain conditions, be employed. These different kinds of material make very smooth and pleasant roads for light traffic, the limestone, alone or in combination with flints, possessing the property of forming a mortar-like detritus which binds the stones together. Excessive moisture, however, produces much mud, necessitating constant cleaning, while during dry weather the surface is covered with dust and is liable to break up. The hardest limestones, often designated as granite, are considered in certain localities to have remarkable wearing properties, under moderate traffic.

131. In France the Administration des Ponts et Chaussées has adopted a comparative numerical value for the quality of the materials used on the national roads. This scale of quality, ranging from 0 to 20, has been formulated from the combined results of experiments, attrition and crushing tests, together with the estimated quantity of materials consumed by a certain amount of traffic. The following is a list of the chief varieties of rock used, with the quality of each kind expressed numerically:—

TABLE XV.

(*Ministère des Travaux Publics, Routes Nationales,* 1893.*)

	Quality.
Porphyry,	varying from 10 to 20
Trap,	,, ,, 16 ,, 20
Basalt,	,, ,, 10 ,, 19
Quartzite,	,, ,, 11 ,, 19
Grès Quartzose,	,, ,, 10 ,, 20
Flint,	,, ,, 8 ,, 19
Quartz,	,, ,, 10 ,, 18
Serpentine,	,, ,, 12 ,, 18
Melaphyr,	,, ,, 16 ,, 17
Diorite,	,, ,, 13 ,, 17
Limestone,	,, ,, 5 ,, 17
Gneiss,	,, ,, 5 ,, 17
Granite,	,, ,, 8 ,, 16
Millstone grit,	,, ,, 6 ,, 16
Amphibolite,	,, ,, 11 ,, 15
Schist,	,, ,, 8 ,, 15
Mica schist,	,, ,, 6 ,, 13
Puddingstone,	,, ,, 4 ,, 8

The wide variation in the quality of rocks classed under the same name is interesting and instructive, the trap rocks 16–20 being the best in the list. It is noteworthy, however, that flint and limestone having a value of 9 and 11·12 respectively are by far the most commonly used on the roads in that country.

132. Experimental research into the properties of stones used in road-making is of the utmost importance to road engineers and others interested in the subject. The microscopical examination of road-stones, therefore, combined with attrition tests and aided by the behaviour of these stones in actual use, promises to solve many of the difficulties which beset their selection; and it may be possible in the immediate future to fix the requisite properties of stones used with greater precision, irrespective of the group of rocks to which they may belong.

With this end in view it is interesting to note that the results of petrological examinations of the properties of many road-stones from all parts of the kingdom, including many specimens from the Continent, in connection with the attrition tests of these stones carried out by Mr E. J. Lovegrove, were published † some time ago, along with photo-micrographs of the rocks. These examinations have been carried out by the petrographer to the

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* *Roads and Pavements in France,* by Alfred P. Rockwell.

† Vide *Surveyor,* 10th Nov. to 28th Dec. 1905, inclusive, and *The Petrological and Attrition Tests of Road-making Material,* E. J. Lovegrove, St Bride's Press, London.

Geological Survey of Great Britain, and present much valuable information, which should be studied by all interested in such matters. Some of the conclusions arrived at are that the hardest and toughest stones combining abundance of a hard mineral, namely, quartz, with a dense fine-grained texture, are the best. Porosity is disadvantageous in a good road-stone. This may be brought about by rocks having a ready cleavage or formed of soft minerals. Alteration (molecular rearrangement), and in some instances decomposition-products, improve the stone, but the reverse may be the case.

It is, however, considered premature, at the present juncture, to draw definite conclusions from these investigations, more especially as certain groups of rocks have been poorly represented in the attrition tests referred to.

It is satisfactory to note that specimens and records of the road-stones tested and examined are to be permanently installed in the Museum of Practical Geology, London.

133. Rock from which road-making materials are produced is distributed over most parts in the British Isles. Many quarries, especially in England, where reliable material is obtained, are worked on a large scale and supply road-stones of different gauge to the surrounding counties; such as Mountsorrel, Clee Hill, Penmaenmawr, and many others. In Scotland, apart from such quarries as those in Aberdeenshire, Kirkcudbright, Ben Awe, Furness (Loch Fyne), Kilsyth, for supplying setts and kerbs, etc., the road-stone quarries are, for the most part, worked by the County Council's staff. Rock-drilling machines are in use in most counties, and the operations have resulted in both economy and efficiency.

In Ireland granite is largely quarried in the counties of Armagh, Down, and Wicklow, while basalt and whinstone are readily obtained and largely made use of for road purposes in the counties of Antrim, Donegal, Down, Londonderry, and Tyrone, limestone forming one-half of the material used for macadam.

As bearing on the subject of supply and demand for cheap and durable materials for macadamizing roads and paving streets, it seems strange that, with an abundant supply of suitable rock for the purpose, this country, especially the counties on the south and east coasts, is still threatened with competition of a permanent nature for supplying these materials from France, Germany, Belgium, and Norway. As a matter of fact, large quantities of Belgian and Norwegian macadam and paving-setts are annually imported into this country which, no doubt, are of good quality, while the price per cubic yard or ton is considerably less than for similar material from Mountsorrel and other quarries in Leicestershire. The Norwegian quarries undoubtedly possess better natural advantages, and workmen's wages are much less than in this country. The effect of railway carriage on the price of these materials also seriously threatens the stone industry of certain counties in this country, and any means by which the cost of land carriage can be lessened and working expenses reduced in the production of paving-setts, and macadam for making and maintaining roads, should be carefully studied. Therefore, any expedient by which retrenchment, however small, is possible, should be practised, by the judicious employment of modern plant and machinery for manipulating and transporting the material, and this would, no doubt, result in large sums of money being saved.

It is estimated that 2½ million tons of material are used annually for road-stone and paving in these islands, the cost of the quarried rock alone amounting to about £130,000, while the value of the finished material is over half a million sterling.

CHAPTER V.

QUARRYING.

134. In the preceding chapter the quality of the rock necessary for preparing road metalling and paving setts has been explained. The methods of procuring or quarrying the material will now be described, while the cost of the operations, depending on many considerations, will be entered into in detail.

The igneous rocks are found in irregular masses and dykes, having innumerable 'backs,' or natural veins and fissures, interspersed through the mass, which facilitate its detachment from the parent rock; these rock masses exist to a depth practically limitless.

135. Opening New Quarries; Drainage; Gravitation.—In opening a new quarry the rock mass should be carefully examined with a view to taking advantage of the inclination of the bed joints, which, for economical quarrying, should dip towards the working face. The drainage of a quarry is also of great importance, and the floor level should, when practicable, be arranged so that the water can be drained from the working face by gravitation. The depth of the 'tirr' or overburden to be removed enters largely into the question of selection, and the amount of stripping necessary for a certain depth of rock face will in most cases determine the site of a quarry. When the overburden is deep, or forms a large proportion to the actual quantity of rock quarried, the cost of winning the stone will be correspondingly high. Gravitation, besides affording drainage facilities, assists to a considerable extent the process of quarrying and the removal of the material to the respective points at which it is to be treated, such as dressing-sheds and stone-breaking machines. By this means unnecessary handling is avoided, and economy promoted in carrying on the operations.

It is sometimes necessary, in order to secure the best quality of rock, as well as to limit the extent of the ground occupied, and also to economize stripping, for a quarry to be worked to a considerable depth below the natural surface. This at times may entail an expenditure for pumping water, in order to keep the floor of the quarry dry, while the lifting or removal of the quarried material by mechanical means in the form of cranes and aërial cableways becomes necessary.

136. Tirring or Stripping.—The tirring or stripping may be removed as necessity arises, or, as in the case where the quarries are worked under County Councils directly, it may be accomplished by the roadmen during frost, when their services can be spared from the ordinary road work.

The earth removed should be deposited at a point not likely to interfere with the future working of the quarry. Attention to this matter will save a considerable amount of trouble and unnecessary expense in lifting it again at some future time. The overburden, when of a tenacious nature, or when it is frozen, may be advantageously broken up by sinking a few holes from 2 to 5 feet in depth, and charging them with some high-grade explosive; on this being exploded the ground will be sufficiently broken up to ensure its easy removal.

137. The simplest method of quarrying is that by which the material can be removed from the parent mass by picks, wedges, and levers. This is, however, only possible in certain quarries, which are by no means numerous, and recourse must usually be had to drilling and blasting.

Hand-drilling or Boring.—The boring or drilling of holes by manual labour, or, as it is termed, *hand-drilling*, is generally effected by either single or double-hand operations. The jumpers, or boring-tools, are for the most part now made from cast steel bars of octagonal section, supplanting those formerly in use made from round iron bars with steeled cutting edges. The cutting edge of the tool may vary in width from 1 to 4 inches, the stocks being of a somewhat less diameter, so as to enable the tool to free itself readily in the bore-hole; this also avoids the introduction of any unnecessary weight into the jumpers.

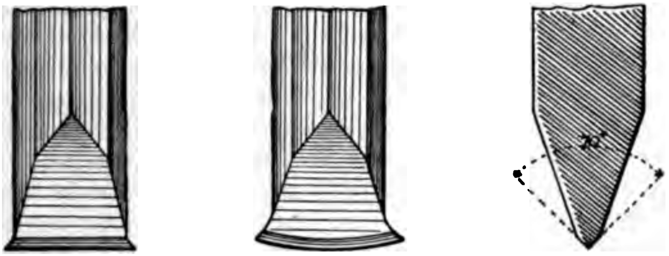
For instance, a boring-tool having a cutting edge of 1 inch in width is made from a steel bar $\frac{5}{8}$ths of an inch in diameter, while $\frac{7}{8}$-inch bars are selected to make a boring-tool with $1\frac{1}{4}$-inch cutting edge, and so on in a similar proportion to tools or jumpers for boring a $2\frac{1}{2}$- or 3-inch hole, which are manufactured from bars of $1\frac{5}{8}$ inch in diameter. The cutting edge of the tool may be made straight or slightly curved for hand-boring; the straight cutting edge, although working more freely than those of the curved form, is somewhat weaker at the corners, and consequently liable to fracture.

Hand-drills and Jumpers.—The straight and curved cutting edges are shown in figs. 47 and 48, while fig. 49 represents a section of the chisel point, the sides of which should not form a greater angle than 70 degrees.

The steel bars from which boring-tools are made are generally cut into varying lengths as may be desired; the tools for boring holes of the smallest diameter are from 18 to 20 inches long, while those for boring holes of greater diameter may vary from 42 inches up to 6 or 7 feet in length. A blow given to a jumper is more effective the shorter the bar, hence it is a common practice to make use of a number of tools, each succeeding one being somewhat longer, while at the same time the cutting edge is slightly reduced in width. The actual diameter of the hole drilled is somewhat greater than that of the boring-tool.

The striking face of the steel or stock should be flat, and in the larger sizes the diameter of the head is made less than that of the stock.

Hardening and Tempering Hand-drills.—The forging and hardening of boring or drill-bits are operations requiring much skill on the part of the smith, so as to avoid the cutting edge and lower portion of the stock being 'burnt,' or the formation of 'water cracks'; and in tempering it is advisable, in order to obtain the best results, to let down the steel to a bright straw yellow.



FIGS. 47, 48, 49.—Boring-tools.

138. Hammers and Sledges.—Hammers or sledges of cast steel are made of varying weights, according to whether the drilling is to be performed by the single-hand or the double-hand method. These vary considerably in shape according to the ideas and customs of the workmen in the different localities where quarrying operations are carried on. The weight of hammers for single-hand boring is generally about 4½ lbs., and as the expression implies, one man in a sitting position performs the whole operation by manipulating both tool and hammer. For double-hand drilling the sledge may be as heavy as 10 lbs., the shaft or helve, generally 30 inches long, being made of a wood having some elasticity, such as hickory, young oak, or acacia; ash is also much used for the shafts or handles of quarry tools.

139. Starting a Bore-hole. Single- or Double-hand Drilling.—The first step necessary in commencing drilling, after the tirring or stripping has been accomplished, is to fix the position of the bore-hole for blasting in the most advantageous manner, regard being had to the natural veins and fissures of the rock as a means of facilitating its detachment from the parent mass. It is necessary to remove any loose pieces of rock and prepare the surface by chipping, so that it may be nearly at right angles to the direction of the intended bore-hole. Double-hand drilling is sometimes performed by two men; one, sitting on the rock, guides and turns the jumper with one hand, and strikes, by means of a light hammer, alternate blows, the other blows being delivered by a second man using a heavy hammer or sledge. The usual, and at the same time most satisfactory method, is for three men to do the work. One man takes up a sitting position and holds the drill vertically between his knees, keeping it in proper position, and turning it partly round, while the other two men strike the head of the boring-bar with sledges, lightly at first, and increasing the force of the blow after the bit has fairly entered the rock. The degree of turn necessary to be given in drilling is one-eighth of a revolution, which prevents the cutting edge falling twice in the same place; by this means the greatest amount of work is accomplished, and a circular form of bore-hole is ensured.

By using water in the bore-hole the drilling is greatly facilitated, the time being reduced by one-third; it also keeps the cutting edge cool, and converts the dust and chippings in the bottom of the hole into sludge, which must be cleaned out by means of a 'scraper' from time to time as it accumulates. In very hard rock a drill may have to be changed frequently, which necessitates the use of several of about the same length; and these should always be in good order and near at hand. The depth to which the bore-holes are drilled by the double-hand method is generally from 5 to 6 feet, sometimes 8 feet; for greater depths up to 10 feet churn-drilling is resorted to when the nature of the rock admits of this being done.

140. Churn-drilling.—The drilling-bar or steel for this method of boring has a cutting edge of different width at either end of the stock, the blow given to the rock being obtained by the direct impact of the falling drill, which is raised by two men to a height of about one foot, and then allowed to drop. In long boring-tools a sufficient weight for the purpose is generally contained in the steel stock, but additional weight may be obtained if necessary by having a bead or swelling fixed on the stock between, but at unequal distances from, the extremities, as shown in fig. 50.

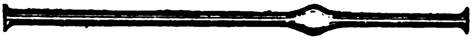


FIG. 50.—Long boring-tool.

The water which is poured into the bore-hole to facilitate the penetration of the bit into the rock is prevented from splashing about, particularly in shallow holes, by placing a perforated leather or india-rubber washer on the shank of the drill at the surface level of the rock. This object may also be accomplished by winding straw round the steel, which should be fixed as in the case of the washer.

The sludge formed during the process of drilling must be removed from time to time as the depth of the bore-hole advances, since the oftener this is done the greater will be the amount of drilling performed in a given time. The rock being exposed to the action of the cutting edge of the tool and the full effect of the blows transmitted to it by the jumper, will not be cushioned, as it would be in the case where the sludge is lying between the bottom of the hole and the edge of the boring-tool. The cleaning out of the bore-holes, when not too deep, is effected by a simple tool called a *scraper*, which consists of a rod of iron varying from ¼ to ½ inch in thickness, and of a sufficient length to reach the bottom of the holes. It is provided with a disc attached at each end of the rod of different diameter, so as to make it suitable for the various sizes of holes bored. Instead of having discs at either end, one of these is sometimes formed with a spiral hook or *drag-twist*, which is very useful, as, by attaching a wisp of hay to it, the bore-hole can be thoroughly wiped dry previous to charging.

141. In the event of the shank of a drilling-tool or jumper being broken by some cause or other while boring operations are in progress, the portion left in the bore-hole may be recovered by various means. The simplest way of accomplishing this is to guide a running noose of cord by the aid of a second drill on to the broken one, and pull the noose tight, when the portion of the drilling-steel left in the bore-hole can be drawn out. Tongs having an arrangement attached for tightening the legs so as to grip the steel firmly are also sometimes employed for this purpose; while another instrument called a *beche*, made of iron, and having a hole at the lower end of a slightly conical shape, which fits on to the top of the broken steel, is at times made use of for the same purpose.

142. If, as often happens in many quarries from which road material is taken, water finds its way through fissures into the bore-hole, it becomes necessary to line it with clay when the explosive agent employed is blasting powder.

This is performed by putting the clay into the bore-hole in a plastic state, inserting an iron tool slightly less in diameter than the hole, and pointed at one end, called a *brill*, and by repeated blows forcing the clay into the joints and crevices of the rock. This instrument, which at one time formed an important part in a set of 'blasting gear,' has now become of less importance by the introduction of waterproof cartridges containing gunpowder, and the nitro-glycerine and gelatinous compounds, which are now much used in blasting operations.

143. Amount of Work accomplished by Hand-boring or Manual Labour.—The amount of drilling or the depth of holes which can be accomplished in one day will greatly depend on the hardness of the rock and the size of the drilling-tool used. Joints and fissures when lying at an angle to the direction of the bore-hole give considerable trouble, and much time is consequently lost, reducing the amount of work below what could otherwise be accomplished under more favourable circumstances. For this reason it is advisable to select the best possible position for the bore-hole, while at the same time due consideration must be given to its position and direction in relation to the portion of rock which is to be dislodged from the parent mass.

The amount of drilling which can be accomplished by hand, in the different classes of rock used for road purposes, varies considerably according to circumstances.

The method of calculating and stating the actual amount of drilling performed will be given in *cylindrical inches*, which is particularly applicable to open quarry work. This system of computing the amount of work done will also be adopted in determining that performed by machine rock drills, which will be described later on. The cylindrical inch has a relative value, and the use of the term is preferable when making a comparison of the amount of work done and the cost of the operation, than by simply stating the number of inches or feet in depth drilled each day. Under the latter circumstances no comparison is possible, as the width of the bit or size of the bore-hole may vary considerably according to the depth drilled, while the length of the working day is at times a variable factor in quarrying operations.

Therefore, by adopting this numerical figure as a standard for the amount of work performed in a given time, a comparison can be more readily arrived at between drilling by manual labour on the one hand, and that accomplished by a machine rock drill on the other, while the drilling capacity of the different types of the latter can also, by this means, be easily ascertained.

In Table XVI. the average amount of work performed by hand drilling is stated in accordance with the preceding particulars. As the length of a day, however, is a somewhat vague definition of time, more especially when the working hours are interfered with by stress of weather, or shortened during the winter months, the hour is adopted from which a day's work of any specified number of hours can be calculated. The figures are taken from the results of actual experience under varying conditions, time being allowed for cleaning out holes and resting.

TABLE XVI.

Rock Drilling by hand: one man manipulating the drill, two men striking with sledges. Bore holes vertical downwards.

	Cylindrical Inches.		
	Per Hour.	7 Hours Day.	10 Hours Day.
	No. 1.	No. 2.	No. 3.
In granite, ...	16	112	160
,, basalt, ...	19	133	190
,, whinstone, ...	21	147	210
,, limestone (mountain), . .	28	196	280

The depth of a bore-hole in inches, drilled in an hour's time, may be found by dividing the figures given in column No. 1 by the square of the diameter in inches of the drilling-bit used. For horizontal or breast-holes the amount stated in Table XVI. will be less by about 30 per cent. It should also be mentioned that the figures in the table are calculated for bits capable of drilling a bore-hole of an average diameter of 1½ inch; for shallow bore-holes of a less diameter, and which are at times required, the amount will be slightly in excess of the figures given.

144. Cost of Hand-boring.—To arrive at the cost of drilling per foot of depth with drills of varying diameters the cost of labour and incidental expenses require to be determined. Taking the average wages at 3s. 8d. for each man per day of nine hours, and allowing 2d. per foot of depth for sharpening the bits on the harder rocks, loss of weight in steel, repairs to hammers and sledges, etc., amounting to say 1s., 12s. will be the total cost for each day's work of one squad of drillers.

The cost of drilling one foot in depth with bits of different sizes, taking 12s. as the actual cost per day of nine hours, or rather over 1s. 4d. per hour, is shown in the following table, which may be taken as a broad average.

Table XVII.

Comparative Statement of the cost of drilling by hand per foot in depth with drilling-bits of varying sizes.

	Diameter of Bore-holes in Inches (average).									
	1½ in.		1¾ in.		2 in.		2½ in.		3 in.	
	s.	*d.*	*s.*	*d.*	*s.*	*d.*	*s.*	*d.*	*s.*	*d.*
Granite, cost per foot. . . .	1	6	1	9	2	0	2	6	3	0
Basalt, ,, . . .	1	3	1	6	1	8	2	1	2	6
Whinstone, ,, . . .	1	2	1	4	1	6	1	11	2	3
Limestone, ,, . . .	0	10¾	1	0	1	2½	1	6	1	9½

Should the total wages per day be more or less than that mentioned, then the figures in the table must be correspondingly increased or reduced, on the assumption that the same amount of work is performed.

When the nature of the rock permits of the bore-holes being put in by means of a churn-drill, the cost per foot, after the first 18 or 24 inches, can, by this method of drilling, be accomplished for about 20 to 25 per cent. less than the cost per foot stated in the table above.

145. The remarkable advance made in recent years in the construction of mechanical rock drills is such that the practice of hand-boring, the only method of former days, has been to a great extent superseded.

The practical advantages accruing from the use of rock-drilling machines in quarrying operations are decidedly great, while the rate of progress made possible by their use has been the means of reducing the cost of production, and greatly extending work in connection with the stone industry.

This applies very particularly to the quarrying of material for macadamizing purposes; and the substitution of mechanical power for hand labour in accomplishing this has been very marked in recent years, while the economy effected by its use enables the quantity of material for repairs amounting to double that possible by hand-boring to be procured for the same expenditure. In other words, the economy effected, on any quantity of material quarried, is 50 per cent. by machine over what can be accomplished by hand-drilling and the attendant expenses of blasting.

Machine rock drills are applied in a variety of ways, according to the work required of them; the arrangement with a tripod for its support will alone be described, as it is the only form employed in boring rock from which the material for making and repairing roads and streets is obtained.

Machine rock drills are actuated in the same way as the drills used in hand drilling, namely, by a succession of blows given to a chisel-pointed tool which is partially turned round between each blow as already described, and known as percussive boring.

Hand-power Drilling Machines.—Hand-power drilling machines have been employed to a limited extent; they are operated by two or three men turning a handle and flywheel conveying to the mechanism the necessary power to cause the drilling-bit to strike two or three blows on the rock for each turn of the handle. In this class of machine the force of the blow is limited, while a considerable amount of power is absorbed by the machine itself through the friction of its working parts. As a machine does not create power, a hand-power boring machine must be lacking in efficiency and economy. Although machines of this particular class have not attained a high reputation, still they may be regarded as the first step in the transition from hand to machine drilling. There can be no doubt that the Sommeiller drilling machine used for piercing the rock during the construction of the Mont Cenis Tunnel is the prototype of the rock drills now in use.

146. Different Types and Requirements of a Rock-drilling Machine.—The numerous types of machine rock drills in use at the present time vary in many particulars, but chiefly in the details of construction rather than in the principle on which they work. Durability is of great importance in a rock drill; any defect in the principle of the mechanism or construction of the parts subjected to considerable strain materially affects the working expenses. The weight should be reduced where not necessary for efficiency and the fitting of the working parts, an important element which may, if not properly designed and manufactured, involve the outlay of considerable expenditure for repairs. Great strength in certain parts of rock drills is essential, considering the rough usage they are sometimes subjected to, while lightness for the sake of portability has also to be considered.

The requirements of a good machine rock drill are given concisely by André in his work on *Coal Mining*, and are as follows:—

1. A machine rock drill should be simple in construction, and strong in every part.
2. It should consist of few parts, and especially of few working parts.
3. It should be as light in weight as can be made consistent with the first condition.
4. It should occupy but little space.
5. The striking part should be relatively of great weight, and should strike the rock directly.
6. No other part than the piston should be exposed to violent shocks,
7. The length of piston stroke should be capable of variation.
8. The sudden removal of the resistance should not be liable to cause any injury to any part.
9. The rotary motion of the drill should take place automatically.
10. The feed, if automatic, should be regulated by the advance of the piston as the cutting advances.

147. Tappet Drills.—From these exacting and admittedly necessary requirements it is evident that the movement of a valve actuated by a tappet situated in the cylinder of a drill does not conform with these rules, since two parts are subjected to violent shocks, namely, the piston and the tappet; moreover, the latter is liable to abnormal wear. Another defect which is invariably present in rock drills having a tappet-actuated valve motion, is that the blow is struck on a cushion of air or steam. No doubt this may occur only to a limited extent if the drill operator is capable of judging the actual length of stroke, a qualification rarely met with in practice; while, on the contrary, there must be considerable cushioning. When this is the case the drill is expending the motive power on itself instead of on the rock. Tappets, especially those made of the double form, are liable to failure through fracture or displacement; it is therefore undesirable to use drills constructed on this principle at a high piston speed, and consequently they are not expeditious cutters.

The tappet drill, however, has a slight advantage over drills with steam-thrown valves, especially when the steam is wet, or where by accident any foreign matter gains access to the working parts, the large openings in this class of drilling machines being capable of discharging these without injury to the valve. A tappet drill with these defects is not a perfect working machine.

148. Rock Drills with Steam-thrown Valves.—Those machines which have steam-thrown valves with a positive action present the best form of construction, as only one part, and that part the piston, is subjected to violent shocks. Most of the earlier types of rock drills, and a large number at present in use, are distinguished by having a tappet-actuated valve, and, as might have been expected, the improvement in the valves of rock-drilling machines has tended in the direction of steam or air-thrown valves. Many other essential features will be noticed later on.

149. Some Types of Drills used in this country.—For obvious reasons it would be impossible to attempt a description of the numerous forms of rock drills constructed and made use of in this and other countries, although many, no doubt, possess points of considerable merit. Of the many rock drills in use may be mentioned the 'Sergeant,' 'Hirnant,' 'New Ingersoll,' 'Rio Tinto,' 'Cornish,' 'Daw,' 'Murdoch,' 'Optimus,' 'Champion,' 'Climax,' 'Adelaide,' and a few types of electrical and hydraulic power drills. Many of these are working in various districts in the British Isles with marked success; the first two, however, will only be described in detail. The Ingersoll-Sergeant is much used in quarries for producing road material; it is also used along with the Hirnant and some of the other types mentioned by contractors on public works.

The Ingersoll-Rand Company also make the 'Little Jap' Hammer Drill for light work, such as plug-holes; they are placing on the market a new form of drill to be known as the 'Electro-pneumatic' Drill.

150. 'Sergeant' Rock Drill.—The 'Ingersoll-Sergeant' or Sergeant rock drill with auxiliary valve, is a development of the 'Ingersoll' and the 'Ingersoll Eclipse' drills, and has been designed for boring hard rock. The general construction and working parts are shown in longitudinal section in fig. 51. The main valve *a* is made of one piece in the form of a small double piston with two wide annular grooves turned in it to admit the steam or compressed air to and from the main cylinder *b*. The travel is produced by means of an auxiliary valve *c*, acting as a trigger to the main valve, but entirely independent of it. It opens or closes the steam or air passages, thereby releasing the pressure from one end or the other of the main valve. The auxiliary valve moves on an arc of a circle through contact with the piston *d*, operating tangentially, and which has a wide annular recess *e* in the middle of its length, with inclined planes at either end, forming a shoulder. The valves are held in such a position that, while the piston carrying the cutting tool is moved towards the rock, the exhaust remains open at one end, the full pressure acting on the other end until the blow is struck, at which time, and then only, the main valve is immediately reversed. By the combination of the spool valve with an auxiliary valve, working in direct contact with the piston, a positive motion is obtained, which ensures the full force of the blow being delivered on the rock, or, as it is termed, a dead blow. This is a special feature of the 'Ingersoll-Sergeant' machine, and gives a distinct advantage compared with those drills which strike a cushion of steam or air in the front of the cylinder and the rock simultaneously, necessarily reducing the cutting power of the drill considerably.

The variable piston stroke, so essential in starting bore-holes, and when the bit is working through seamy rock lying at a considerable angle to the direction of the bore-hole, is obtained by simply turning the crank and feeding the machine towards the rock. This is an important point, as by feeding the drill-bit up to within an inch of the rock a hole can be started with great ease, and in one-half the time occupied by a rock drill working on a full stroke. It may also be observed that in rock-drilling machines which have not a variable stroke, the bit is liable to have the corners broken by reason of the long stroke when striking on a slanting face. When this does not occur the bore-holes which are commenced under these conditions with a glancing blow, invariably drill a hole out of line with the machine, necessitating in most cases its being altered to coincide with the changed position of the intended bore-hole.

The liability of a drill-bit to stick or become jammed when passing through fissured rock presents itself in a greater or less degree in most quarries from which rock is obtained for road purposes. It is essential, therefore, that a drill should be capable of exerting sufficient power to loosen or withdraw the bit easily. This is provided for in the 'Ingersoll-Sergeant' drill by a sufficient annular space affording the necessary area for pressure on the front end of the cylinder, by which means it is capable of not only making the return stroke, but of lifting or recovering the drill-bit from broken, crooked, or muddy bore-holes. The piston, besides being made of steel and hardened, fits plug-like in the cylinder, and is provided

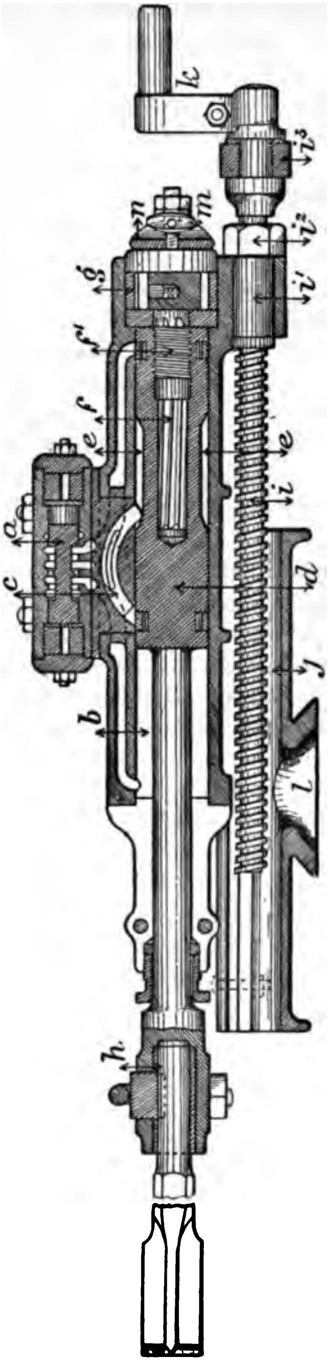


FIG. 51.—Ingersoll-Sergeant drill (longitudinal section).

with piston rings made in two pieces with an elliptical spring underneath to keep them tight to the bore of the cylinder, thus preventing leakage past the piston.

The means employed to give a rotary motion to the drill-bit on its return stroke is shown at *f* and *g*, fig. 51, and in detail at fig. 52, and consists of a rifle or spiral bar *f*, having deep-cut groves working through a bronze-nut f^1 screwed firmly into the end of the piston, and fitted at the back head end with a ratchet wheel *g* with internal teeth. Two pawls, g^1, press against the ratchet teeth, and are kept in position by spiral springs having a straight line movement. It will be observed that the piston carrying the drill-bit assumes by this arrangement a new position after each stroke.

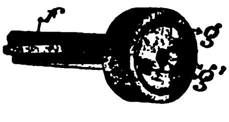


FIG. 52.

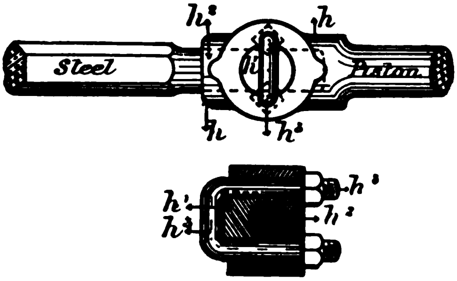
The drill-bit in striking an uneven surface has at times a tendency to turn the steel or shank in a direction opposite to that in which it should rotate. Should this occur in a power-drill having a rigid rotating mechanism, the probable result will be that the spiral bar would be twisted or the ratchet teeth and pawls broken. In the 'Ingersoll-Sergeant' drill the effect of such a contingency is obviated by a release movement, brought about by the washer at the back head being simply turned round, thus overcoming the friction caused by the pressure of the back head springs. This device is undoubtedly an ingenious piece of mechanism, and being perfectly designed, is not liable to injury, an all-important matter during drilling operations.

It often occurs in drilling rock, that the bit, in passing through seams, encounters a soft part which causes it to penetrate suddenly, or advance rapidly, the result being that the piston strikes the front head of the drill. To obviate any possibility of damage through this cause two steel springs (*n*, fig. 51) are placed on the back head and connected with the front head by means of side bolts, thus cushioning the blow resulting from the drill operator neglecting to feed the machine properly.

This is at once a simple and thoroughly efficient method of preventing the breaking of the cylinder covers, and much preferable to and less expensive than the device generally adopted on many rock drills, where india-rubber buffers or cushions are made use of.

The manner of fixing the drill-bit steels is a matter of considerable moment, when it is considered that they have to be changed repeatedly during the progress of a deep bore-hole. The forward or feed motion of the drill described is 24 inches, necessitating the use of drill steels advancing in length by 2 feet. It will be obvious that should the time occupied in changing the steels be great, the time actually engaged in drilling by the machine will be correspondingly reduced.

It is therefore very desirable that the changing of the steels should occupy as short a time as possible, and the mode of fixing them be simple. As the vibration of a power machine when at work and the strain on the drilling steel is necessarily great, it is quite as important that the steel should be firmly fixed. The means of attachment is effected by inserting the end of the steel into a socket 5½ inches deep and 1⅛ inch diameter in the chuck end of piston, which is swelled out for this purpose. The arrangement of the chuck *h* is shown at figs. 53 and 54. The piston bushing is slotted, a round key h^1 fits into the slot and presses against the shank of the drill steel h^2, and the whole is held firm by a U-shaped bolt h^3. It is easily managed, while little time is necessary for loosening the two nuts, and for substituting one steel in place of another.



Figs. 53, 54.

The forward movement is given by the feed screw *i*, which has a large square thread, working through a feed nut i^1, and having a binding nut i^2 in the cross-heads of the cradle *j*, by turning the crank handle *k*. The guides of the cradle are made square and of suitable dimensions; provision is also made for enabling any side play or slackness arising from wear being properly adjusted.

The machine is fixed on to the mounting or tripod by means of the conical spigot *l*, which is cast on the under side of the cradle.

The oiling of the valves and piston is provided for by an oil cup, placed between the throttle and steam-chest, the lubricant, preferably a heavy mineral cylinder oil, being thrown into the working parts in small quantities when necessary.

A small aperture with thumb-screw *m* at the back head provides for the oiling of the rotating mechanism.

From the preceding observations it will be readily understood that in a rock drill the positive valve motion, variable stroke, and effective rotation mechanism tend to give it efficiency in working and to promote economy in repairs. The 'Ingersoll-Sergeant' drill, according to André, fulfils in a remarkable degree the necessary conditions already alluded to, and it may therefore be looked upon as a nearly perfect rock drill. It is very compact, lightness and strength being a characteristic feature in its construction. These rock drills are made in various sizes, according to the nature of the quarry operations undertaken; the drill with a cylinder of 3¼ inches in diameter is a very serviceable machine and can be easily handled, as its weight is only about 2½ cwts.; the tripod weighs 1¼ cwts., and each weight for the tripod, 1 cwt.

Bore-holes 14 to 18 feet deep can be easily drilled by this size of machine. It is the kind used in many stone quarries, and by the County Councils in Scotland. A machine for drilling deeper holes is also used in sale quarries, the cylinder of which is 3½ inches in diameter. The latter machine weighs 260 lbs. without the tripod, and can easily bore holes 20 to 25 feet deep, which in some quarries is a decided advantage.

151. 'Hirnant' Drill.—The other rock drill to be described is known as Larmuth's or the 'Hirnant' drill, a longitudinal section of which is shown in fig. 55.

The leading feature of this drill is, that the valve is actuated by a tappet rocking on a pivot, which works in contact with the piston. The valve box, which, in the earlier type of this machine, was made very long, has one of three arms of the tappet fitting into a recess in the valve spindle which carries the D-shaped valves. This arrangement, however, proved defective, owing to the breaking of the valve spindle by the sudden shock which it was subjected to when at actual work.

A shorter valve box is now substituted, the spindle dispensed with, and a solid piston valve *a* used in its place, obviating the defect existing in the former drill. The tappet *c* is, however, retained to ensure certainty of action and to lock the valve in position.

The piston *d* is turned to fit the cylinder *b* exactly, neither piston rings nor packing being made use of. The wearing of the piston and cylinder must in time admit of steam or compressed air leaking between them, but this does not materially affect the working parts, although its efficiency generally must necessarily be impaired. India-rubber buffers, *n*, are employed at either end of the cylinder to destroy the momentum of the piston in case of overshooting. When compressed air is the motive power employed to work this class of drill, these buffers wear quickly by being acted upon by the oil used in lubricating the cylinder, and when steam is used to operate it, the combined action of these destructive agents wears out the buffers quickly, and necessitates frequent renewals.

The action of a tappet-actuated valve, as already pointed out, must to a certain extent strike a cushioned blow, thereby expending a considerable amount of the force on the machine itself, instead of striking the rock directly. For the same reason, in a tappet drill a variable stroke can only be obtained by working on a cushion of air or of steam.

The rotary motion in the older type of this drill was obtained by means of a twisted square bar; this arrangement, however, not proving quite satisfactory, a grooved or spiral bar *f* has been substituted. This works through a nut in the back head of the drill, turning the cutting tool round at each stroke, and is secured by means of a ratchet and pawl *g*.

The feed or forward motion is provided for by a long screw, *i*, having a square thread passing through nuts i^1, and supplied with an arrangement for taking up the wear. The method of fixing the cutting tool or steel to the lower end of piston was attained in the earlier machines by means of a bolt passing through the chuck in which the shank of the bit was inserted, and likewise through the steel itself, being tightened by a nut as shown at *h* in fig. 55. A new method of securing the drilling-bit is made by forming the shank with a taper and fitting this into a conical recess in the chuck end of piston, wedge fashion, as represented in fig. 56. This arrangement, however, is not satisfactory when drilling in seamy rock, as the steel works loose on being hammered, a process which is necessary under these circumstances.

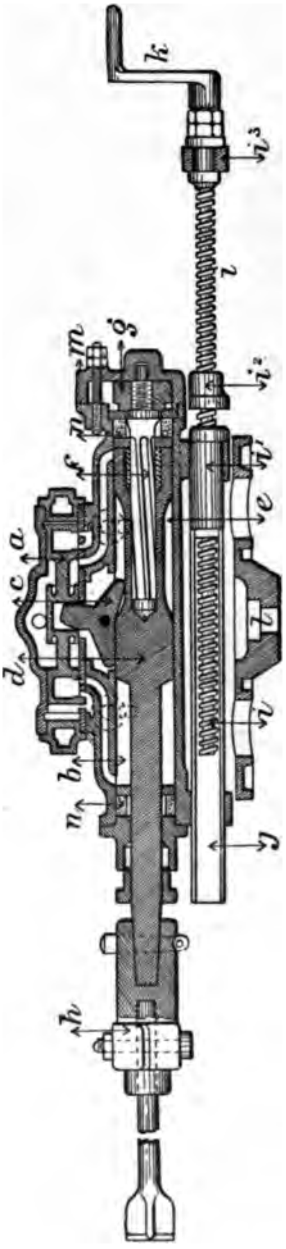


FIG. 55.—Hirnant drill (longitudinal section).

The 'Hirnant' drill is constructed in a very solid manner, the object of the makers being steady and permanent work. It is not a speedy boring machine in large or deep holes, and, generally speaking, requires few repairs. Very good work can be accomplished with this machine, providing the drill-runner exercises skill and intelligence so as to utilize the full power of the machine; if he works with a reduced stroke on a cushion of steam or of compressed air, he is simply spending power in pounding the drill itself instead of applying it against the rock to be bored.

The force of the blow in a tappet drill is materially checked by the too early admission of the steam or compressed air, which forms a cushion in front of the piston; the work accomplished will therefore be small in proportion to the power consumed, although the piston may be travelling at a great speed.

Greater skill is required for operating a 'Hirnant' drill than is necessary for working one on the 'Ingersoll-Sergeant' principle. There can be no question that the results claimed for the 'Hirnant' machine have been attained, but the fact undoubtedly remains that rock drills which have a tappet action strike a blow on a cushion of air or steam, and, therefore, cannot deliver a dead blow. Further, a cylinder of larger size in proportion to the width of bit is required for drilling the bore-hole, or if it be of the same size, the cutting capacity must necessarily be reduced. The 'Hirnant' drill, notwithstanding the defects common to all drills of the tappet type, has been largely used by contractors in this country for tunnelling and other public works.

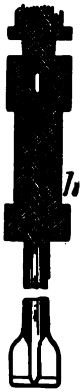


FIG. 56.

152. Compound Rock Drills.—The principle of expansion has been introduced for the purpose of further economizing the motive power in rock drills, but hitherto without much success. The difficulty has been the greatly increased size and consequently heavier machine necessary, which counterbalances the advantages which lightness gives for quick and easy handling. What may be gained in economy of power by compounding is lost in the time occupied in moving the heavier machine from one bore-hole to another. In addition to this the expanded steam frequently has insufficient power to withdraw the drill steel from a bore-hole, in seamy rock, without admitting live steam, thereby counteracting the benefit derived from compounding.

153. Tripods.—The support or mounting to which a rock drill is attached for the system of quarrying under review is that of a tripod, which constitutes a very important adjunct to the machine. For many reasons it must be of light weight for convenience in handling, and of strong construction, so that great rigidity may be attained. A point of the utmost importance is that it should admit of the drill being readily adjusted to any angle so that the holes may be bored in the direction and with the inclination required, and when so fixed permits of the feed or forward movement taking place.

It is also necessary that the tripod should be constructed so as to admit of its ready adjustment to the irregularities of the surface of the rock met with in quarry work. A drill support which does not possess these distinctive requirements is placed at a great disadvantage, and under certain circumstances may necessitate the employment of hand-boring to supplement the work done by the machine drill. It is obvious that a rock drill and mounting which cannot be so fixed as to accommodate itself to the extreme irregularities of rock surfaces is detrimental to success, and would under such circumstances be restricted in its operations as a labour-saving machine.

A rock drill may have a perfect valve motion, and be otherwise of good design, but may fail to do efficient work by reason of the defective construction of the tripod, which incompleteness constitutes in many cases a serious objection to the adoption of a rock-drilling machine.

The form of tripod used in connection with the 'Ingersoll-Sergeant' drill is shown in fig. 57.

The saddle bolt *o* which carries the hip rings *p* and to which the legs are attached ties the whole appliance together, and by loosening it the legs of the tripod can be thrown into any position, at right angles to the bolt. The front legs *q* are further provided with a bolt *r* (attached to the hip ring), the loosening of which enables the position of the legs to be altered from that of a right angle to a parallel position in relation to the saddle bolt. The front legs *q* and back leg *v*, consisting of tubing, are pointed at the lower end; they are made telescopic and are provided with bands and set screws *s*, so that the legs can be adjusted to the irregularities of the rock surface.

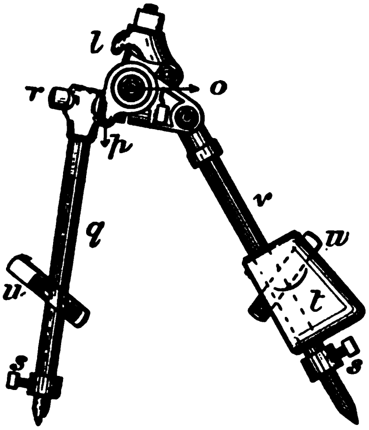


FIG. 57.—Tripod for 'Ingersoll-Sergeant' drill.

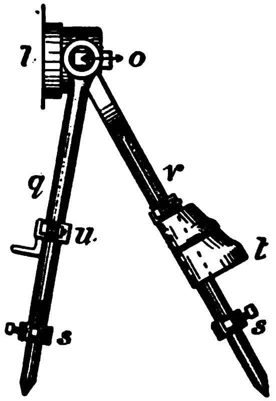


FIG. 58.—Tripod for 'Hirnant' drill.

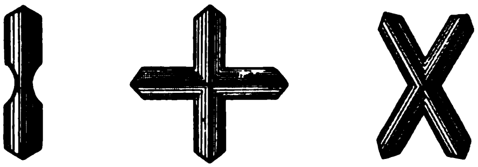
When the machine is working the tripod should be perfectly rigid, for which purpose weights *t* are attached and kept in position by weight hangers *u* fixed to the legs at an angle as shown in fig. 57.

The arrangement of the tripod in connection with the 'Hirnant' drill, fig. 58, and indeed with most of the other types of rock drills used, is somewhat similar to that described, but the front legs *q* have only one movement, namely, at right angles to the saddle bolt *o*. In addition to this the use of slides and bolts greatly complicates and, at the same time, weakens the tripod, and naturally makes it non-efficient. By having an arrangement similar to that of the tripod for the 'Ingersoll-Sergeant' drill, and known as the universal joint, the drill can be so placed as to drill holes in the most advantageous position for blasting, not attainable by other drills of which the tripods have only one movement.

The weight of the 'Hirnant' drill and tripod described is 3 cwts., and the three weights about 1 cwt. each. The cylinder is 3½ inches in diameter, and can bore holes 10 to 12 feet deep, the width of drill-bit or size of bore-hole at commencement being 2½ inches.

154. Drill-bits.—The width of the cutting edge, the form given to a drill-bit, and the diameter of the steel used, vary according to the nature and character of the rock to be bored and the capacity of the drilling machine employed. A judicious selection of the best shape of bit, suitable for the rock, adds considerably to the success of the boring operations with drills actuated by steam or compressed air. The chisel-pointed bit usually adopted in hand-boring has no place in machine drilling when the rock is fissured. A modified form of this kind of bit is shown in fig. 59; it answers very well for sandstone and slate of a solid nature. The flattened or grooved portion at the centre of the bit is made for the purpose of discharging cuttings and sludge.

The part forming the centre of any drilling-bit performs but little work, so that the reducing of the steel, as shown, does not affect its efficiency. The steels for the smaller sizes of rock-drills are generally made from ⅝ths of an inch to 1 inch in diameter, while for the larger-sized machines the diameter varies from 1⅛ inch to 1⅝ inch. They are made from octagonal steel bars; the shank, or part which fits into the bush of the chuck at the end of the piston, is turned so as to fit it exactly, the top end being made of a hemi-spherical shape. The width of the cutting edge is determined by the size of rock drill used, that is, by the diameter of the cylinder, or in other words, by the force of the blow transmitted by the machine to the bit. It varies from ¾ of an inch to 3 inches for general quarrying, while in special circumstances it may be as wide as 5 inches. The proper shape to be given to a drill-bit, under varying conditions of work, is a subject on which a considerable amount of attention has been bestowed.



FIGS. 59, 60, 61.—Drill-bits.

The cross-bit shown in fig. 60 is a decided improvement on the older form or chisel-pointed bit, and does very good work in solid rock. There is, however, a difficulty with this form of cutting edge, arising from the circumstance that when rotated by means of the spiral bar it has a tendency to strike the same place four times in each rotation. This unavoidable pounding of the drill-bit on the same spot, especially when it is penetrating the rock quickly, has a tendency to bury the bit in the same groove, with the result that the succeeding blows will cause the bore-hole to be 'rifled,' or of an irregular shape.

The drill-bit made in the form of an X, fig. 61, is now almost universally adopted with percussive rock drills, as from the shape of the cutting edge the chance of striking the same place is reduced by one-half; consequently there is less risk of the hole becoming rifled. Attempts to bore a round hole with the cross-bit have often failed, while the X-bit has performed the work satisfactorily in this respect. The drill-bit in cutting its way through seamy rock has a tendency to run out of line, or to follow the fissured parts, which may be at a considerable angle to the direction of the bore-hole. This causes great trouble, and may necessitate the work of drilling the hole being abandoned before the intended depth has been reached. It also entails a considerable loss of time in shifting the machine, and, if the abandoned bore-hole is not very deep, an additional one may be required to successfully carry out the blasting of the rock. It will be evident that under such circumstances the working expense in drilling on a certain piece of rock may be greatly increased from the cause mentioned. To obviate this, the drill-bits should be formed with shoulders or wings extending back to about 6 or 8 inches from the cutting edge, and only of a slightly reduced diameter at the rear end of the wings, so as to ensure free working. As the cutting edge wears in proportion to the amount of work done, it is advisable to have wings of the length mentioned.

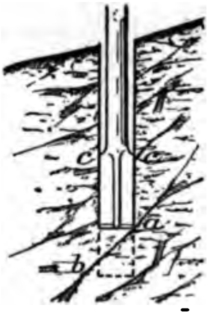


FIG. 62.

The purpose of these wings will be more clearly understood by referring to fig. 62. The cutting edge of the drill-bit, in penetrating the seams running diagonally across the hole, will, if not prevented, follow the line or vein *a b*. This is obviated by the wings being in contact with and guided by the sides of the bore-hole *a c* and *b c*, which check the tendency of the cutting edge of the bit to follow the slanting direction of the seamy or fissured portion of the rock *a b*.

155. Tempering Drill-bits.—The hardening and tempering of the drill-bits is a matter requiring careful study and observation on the part of the quarry smith. In hardening drill-bits, it is desirable to combine as far as possible the properties of hardness and toughness.

Hardness is produced by immersing in water a part of the bit, the steel of which should be of the best material, after it is heated to a certain temperature; this is the cooling medium employed, while toughness may be increased by immersing the bit in oil, which process should be occasionally carried out to prevent the steel becoming too brittle. The drill-bits are first dressed to the proper form and gauge by means of special blacksmith's tools, viz., a dolly, sow, spreader, flatter, and swage. The quarry smith does not like to dress an X-bit, as that involves considerable trouble and manipulation; this difficulty may, however, be easily overcome by using two dollies. The drill-bit, when intended to be made in the form of an X, should be dressed first as a cross-bit; the requisite shape can then be obtained by spreading the wings with a hammer, and finishing it in the X dolly immediately before commencing the hardening process. The hardening of the cutting edge is proceeded with by heating the end of the steel to cherry redness, and then dipping it in cold water to a depth of about an inch, moving the bit at the same time slightly up and down to avoid the hardness terminating abruptly. When the requisite degree of hardness has been attained the steel is immersed in water until the heat is reduced sufficiently for tempering. The steel is then withdrawn and the colours carefully watched for, until that of a pale straw appears, which, generally speaking, is the one most suitable for percussive rock drill-bits.

The temperature increases at the point, owing to the heat which is left in the stock passing down, the colours appearing in regular succession on the bright or filed surface of the bit. When the straw colour appears, which can be only properly observed in a dark place in the smithy, the steel is plunged into water and left there till cold, when the process of tempering is completed.

156. Motive Power.—Compressed air or steam is conveyed to the drilling machine by small iron pipes or gas tubing. When there is more than one drill at work, T branches are placed on the line of main pipe at suitable intervals, and laid to within a short distance of the drilling machines. The connection is completed by using a suitable length of metallic flexible tubing or of seamless rubber hose, preferably 5-ply, which will withstand the pressure of steam or compressed air; the exterior should be protected by being marline-wound, and each end should be provided with proper couplings for attachment to the piping and the drill. When it is necessary to connect two lengths of iron pipes for conveying the motive power which do not lie in the same straight line, a flexible ball-and-socket joint is employed, admitting of a movement of about 45 degrees in any direction. By the use of one or more of these flexible joints on a line of piping many delays in changing pipes are avoided, while they remain, especially Moran's patent joint, perfectly air and steam-tight after many years' service.

157. Comparative Trials of Rock Drills.—Comparative trials of power rock drills have been carried out from time to time, but it must be confessed the results have been of little practical value. At the exhibition of Mining and Metallurgy, held in the Crystal Palace, Sydenham, in 1890, a trial was carried out with power rock drills actuated with compressed air supplied at a pressure of about 60 lbs. per square inch, one of the conditions enforced being that the diameter of the bore-hole should be equal to half the diameter of the cylinder of the drilling machine. The blocks of stone operated on were faced so as to give each machine an equal opportunity in starting the bore-hole, two minutes being the time allowed to test the boring capacity of the drill. So limited a period of time for such a trial, be it observed, does not admit of any practical comparison being made between different types of rock-drilling machines. For instance, the drill-bit might not be properly hardened and tempered for the class of rock being operated on, and consequently the capacity of the machine would be determined by the suitability or otherwise of the condition of the cutting edge. As a rule the drill is applied in actual practice to a sloping, not a dressed face of rock, so that a drilling machine having a variable stroke could not show its efficiency to the same extent in the latter case as in the former. Rock drills were tried in Cornwall under the conditions given in the foregoing paragraphs, as long ago as 1867, and in an open quarry face ten years later.

The relative merit of a rock drill must of necessity be that of actual work accomplished, whether in a mine, heading, or open quarry work, and the capacity or cutting power and general handiness of the machine can only be determined by an everyday experience extending over a considerable period of time, and under the ever-varying conditions which present themselves in quarrying operations.

158. Position of the Bore-hole.—The selection of the best position for bore-holes is a very important factor in quarry work, as the useful effect or result of the blasting operations depends on a judicious choice in the location of a series of them. To determine the position of each bore-hole properly, it is necessary to consider what effect the action of an explosive will have in relation to the bore-hole and the bounding faces, and also to have a previous knowledge of the probable direction of the natural backs or fissures in the rock. The most favourable condition for blasting is when the rock presents an unsupported face on every side, but in ordinary quarry work this condition does not obtain, the wall or face of the rock being vertical or nearly so; only two free faces exist, namely, the top and breast of the rock. Under these conditions the bore-holes should be placed as nearly parallel to the longest free side as possible. The effects of disruption by blasting may be gathered from the line of fracture as shown in fig. 63, in which *d*, *a*, *f* represents the top of the rock, and *d e* the face, while the bore-hole is shown at *a b* and the explosive at *c*, *w* being the distance from the charge to the face of the rock or the line of resistance. The effect of the charge *c* when exploded, provided it be strong enough, is such that the lines of rupture will follow the bore-hole *a b* and the portion *w c*, while the dotted line *f, b, e* represents the probable crater. The distance *w*, or line of resistance, should not be more than three-fourths of the depth of the bore-hole, so that when charged the lines of least resistance from the centre of the charge *c*, *a c*, and *w c* may be approximately equal.

Fig. 64 represents the plan of the top bench of a quarry; the face of the rock is shown at *b d*, and the bore-hole at *a*. The result of the blasting will depend upon the angle made by the lines of rupture *a b* and *a c*, which must necessarily be less than 180°, and may indeed be a very small angle.

This would be the result if the shot-hole was fired singly, but experience shows that by firing several charges simultaneously, a greater useful effect is obtained. For example, consider another bore-hole the position of which is parallel to the rock face and placed at *a′*; the lines of rupture, taking them if fired singly, would follow the dotted lines *b, a, c* and *c, a′, d*, whereas, if fired simultaneously, the mass of rock which would be dislodged is represented by the letters *b, a, e, a′, d*. The distance between the points *a* and *a′* should not exceed the depth of the bore-holes, the best results being obtained when the distance between them is made equal to the line of least resistance *w*, in fig. 63. It will be seen that the useful effect is greatest when the disruption takes place at an angle of 180°, that is, when the lines of rupture run in opposite directions, showing the decided advantage which may be obtained by firing several shot-holes simultaneously. In firing single shot-holes, the useful effect diminishes as the angle made by the lines of rupture becomes less.

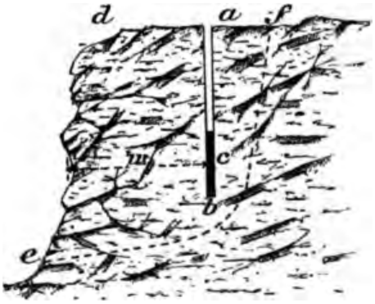


FIG. 63.

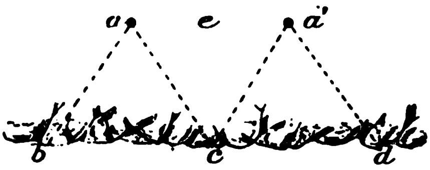


FIG. 64.

Briefly, these are the conditions necessary to be observed for the advantageous placing of bore-holes. As a mass of rock, however, is seldom homogeneous in composition or uniform in texture, a careful examination of the quarry is essential, so that the position and direction of the bore-holes shall be determined in accordance with these varying conditions, in order to produce a maximum effect with a given quantity of explosive.

Machine bore-holes may be drilled either in a vertical, inclined, or horizontal position.

The vertical position is the most convenient for quick handling and drilling, while in blasting, the explosive effect is wholly expended in shattering and dislodging the rock, none of it being required for lifting it. The face of a quarry, therefore, when of considerable depth, should be formed in benches, the level portions being from 12 to 15 feet wide. The depth of face may be varied according to the drilling capacity of the machine employed, the usual depth being from 14 to 20 feet, as shown in fig. 65; the dotted lines show the assumed line of the face as the quarrying operations are extended.

Horizontal, bottom, or breast bore-holes can be made with a modern rock drill. In many cases all these kinds of holes may be required in order to allow of the maximum quantity of rock being dislodged by one operation in blasting, and also of the bottom of the quarry being taken out in as uniform a manner as possible. In a quarry having a vertical face of from 22 to 24 feet, and operating with a drill capable of putting down 14-feet bore-holes, it becomes necessary to place horizontal holes at the floor level of quarry, so as to ensure the dislodgment of that portion of rock which is left beyond the crater formed by the blasting of the 14-feet vertical bore-hole. Vertical shot-holes require a smaller charge of explosive to dislodge a given quantity of rock, compared with that produced from a horizontal or breast hole, the reasons for which will be explained when dealing with the subject of blasting the shot-holes.

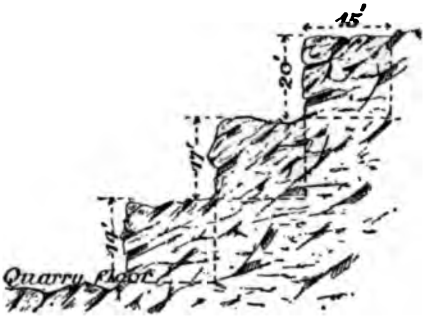


FIG. 65.

From the foregoing observations the position and direction of the bore-holes calculated to give the greatest useful effect in the blasting of the rock may be determined.

159. Previous to commencing drilling operations it is necessary to strip or lay bare such a surface-width of the rock as will remove all the tirr likely to interfere with the actual quarrying operations. The area to be stripped will depend on the quantity of material required, and on the height of the rock face. It may be determined by calculating the contents of the rock in the solid, allowing 13 cubic feet for each ton of material. In general, the stripping may be done as occasion requires, whether the quarries are worked constantly or interruptedly. The expenditure incurred in performing this work should be charged against the total quantity of rock removed from the area cleared. The cost of tirring or stripping per ton of rock obtained will depend on the depth removed compared with that of the rock face, on the method adopted in removing the soil, and on the distance to which it has to be conveyed for disposal.

160. Examples of Quarrying taken from Actual Practice.—In the following example taken from actual practice the quantity of material required was 1500 tons, the depth of rock face being 20 feet; it was desired to determine what width would be required when the length of face is known. In fig. 66 the positions of the bore-holes are shown, Nos. 1 to 9 inclusive being vertical, and 10 to 14 horizontal or bottom holes, the length of face being 40 feet. These bore-holes were all drilled to a depth of 14 feet, and placed at an average distance apart of 11 feet, the measurement from the face of the rock to the first line of bore-holes being the same. The bore-holes in the second line were placed 9 feet further back and parallel with those in front. The distance from the face for stripping purposes is determined in the following manner: the total quantity of rock required is divided by the length of face multiplied by the depth of the rock, which in this case is about 20 feet. An allowance, however, must be made for the line of rupture extending beyond the position of the bore-holes, as the necessity of clearing the soil well back from this point to avoid its falling on to the quarried material is obvious; it is therefore advisable to make the width greater than the calculated figure by 6 or 8 feet. Fig. 67 is a cross-section of the quarry face, showing the position of the vertical and horizontal bore-holes; the actual line of rupture, or crater form, of the mass dislodged is shown by the line *a*, *b*, and *c*.

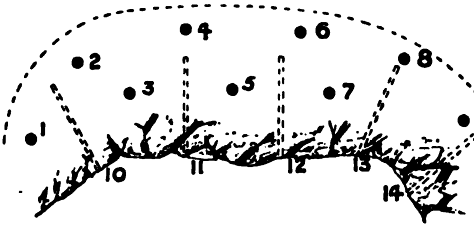


FIG. 66.

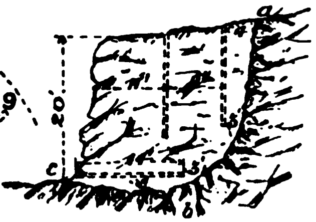


FIG. 67.

Fig. 68 is another example representing road-stone quarry No. 1, where the depth of the rock varied from 27 to 40 feet. In this case it was imperative to blast the total quantity required (4000 tons) at one operation, so that a system of bottom and breast bore-holes in conjunction with the vertical ones became necessary, whereas under ordinary circumstances it would have been worked in benches from the top of the rock surface downwards. It is usual to mark off roughly the area of the rock surface which must be operated upon to produce the quantity of rock required for a given length and depth of face. It will be observed that many of the breast and bottom holes are shown at a considerable angle to the general line of the quarry face; this was necessary, owing to the position and varying direction of the veins and fissures running through the rock mass.

The bottom holes are indicated by the numbers 1 to 13 inclusive; the breast-holes, at an average of from 7 to 10 feet high above the floor level of the quarry, are numbered from 14 to 22 inclusive, and the top or vertical holes, 23 to 42. Fig. 69 represents a cross-section at A A on plan, and shows the method adopted in arranging the position of the bore-holes. They were all put in 14 feet deep and charged with dynamite; the total quantity of material actually quarried and passed over the steelyard amounted to 4158 tons.

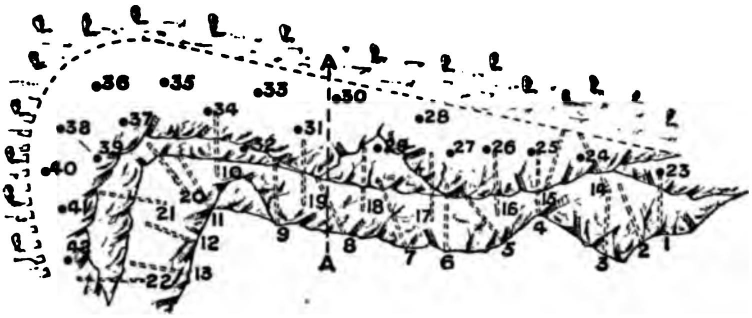


FIG. 68.—Road-stone quarry No. 1.

There is no universal rule for placing bore-holes. The best plan is to study the conditions already mentioned, carefully note the position, depth, and direction of the bore-holes relatively to each other, and the results obtained from previous blasting operations. The number of bore-holes required will depend on the tenacity of the rock, on the development of the joint planes, and, in some measure, on the lines of fracture started by the preceding blast. With electrical firing, bore-holes can be placed further apart, consequently fewer are required to effect similar results.

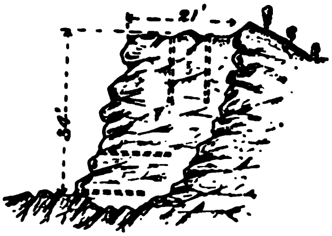


FIG. 69.—Cross-section of road-stone quarry No. 1 at A A.

161. In quarrying for 'dimension stones,' such as those used for kerbs, channels, and setts, the system of drilling few holes is usually adopted, but these are made deep and of large diameter, the object being to apply the blasting agent so that it will simply push the mass of rock outwards and yield the largest blocks possible. In obtaining materials for macadamizing purposes, however, it is of primary importance to reduce the mass of rock to a suitable size for handling; and therefore a large number of bore-holes are drilled, while the explosive used should be specially adapted for the end in view, which will be noticed under blasting.

162. Boring the Shot-holes.—The position and direction in which a bore-hole is intended to be drilled having been determined, the tripod is so placed that when the drill proper is attached and fixed to the saddle the chuck end of the piston carrying the cutting tool will coincide exactly with the spot selected for the bore-hole. In drilling vertical, and even at times bottom bore-holes, it is a common occurrence to encounter loose rock, which should be cleared away previous to fixing the position of the machine. The setting of the tripod for vertical holes is commenced by placing it in an approximate position with the saddle at a fixed height or distance from the rock. The irregular or rough nature of the surface may necessitate placing the legs of the tripod at different angles and of varying lengths. This is readily accomplished by means of the saddle bolt, front leg bolt, and the telescopic pointers fixed by bands and screws. A small hole is made in the rock at three points with a chisel or quarry pick for the pointers of the tripod to sit in. The jaw of the saddle at the apex of the tripod is loosened, and the conical spigot attached to the cradle of the drill is then placed upon it, and properly secured.

The position and direction of the bore-hole are then definitely fixed, all the bolts of the tripod being tightened, and the weights placed on the legs by means of the hangers or clips, which keep the drill perfectly rigid when working. Fig. 70 shows the machine drilling a vertical hole.

In drilling bottom or breast-holes the tripod legs are placed so that they are in a flat position, the under part of saddle resting on a block of wood. The pointers of the two front legs are placed against the rock face, while the other, or back leg, is placed directly behind the line of the bore-hole to be drilled, and is prevented from receding, by reason of the action of the drill, by wedges or by a heavy block of stone.

The weights are fixed on all the legs in a manner similar to that adopted in drilling a vertical bore-hole.

Fig. 71 shows the machine drilling a horizontal or breast-hole.

The first length of steel is then placed in the recess or chuck end of the piston, and properly tightened by means of the U-bolt and nuts. This operation has to be performed as each succeeding length of steel is required.

The connection between the pipes conveying the motive power, whether steam or compressed air, is made by a suitable length of heavy hose marline wound for the former, and wire armoured when compressed air is used. Before attaching the hose to the drill it is advisable to turn on the steam or air temporarily, and clear out any foreign matter which may have by accident gained access into the feed pipes or connections, thereby minimizing any chance of injuring the working of the valve. In commencing the drilling of a bore-hole, whether the rock is at right angles or in a slanting direction to the axis of the drill-bit, it is advisable to go slow at first; this is accomplished by feeding the machine with the cutting tool up to within

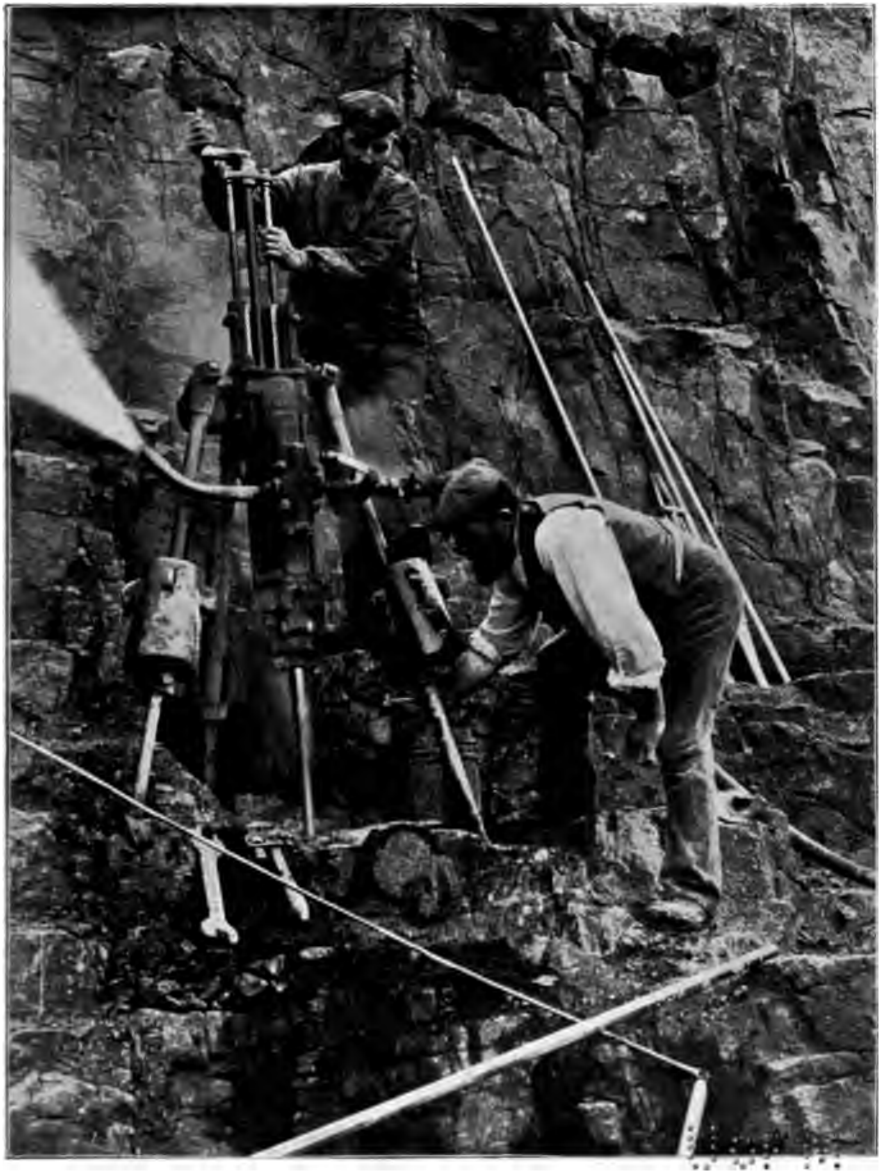


FIG. 70.—Machine drilling vertical bore-hole. [*To face p.* 152.

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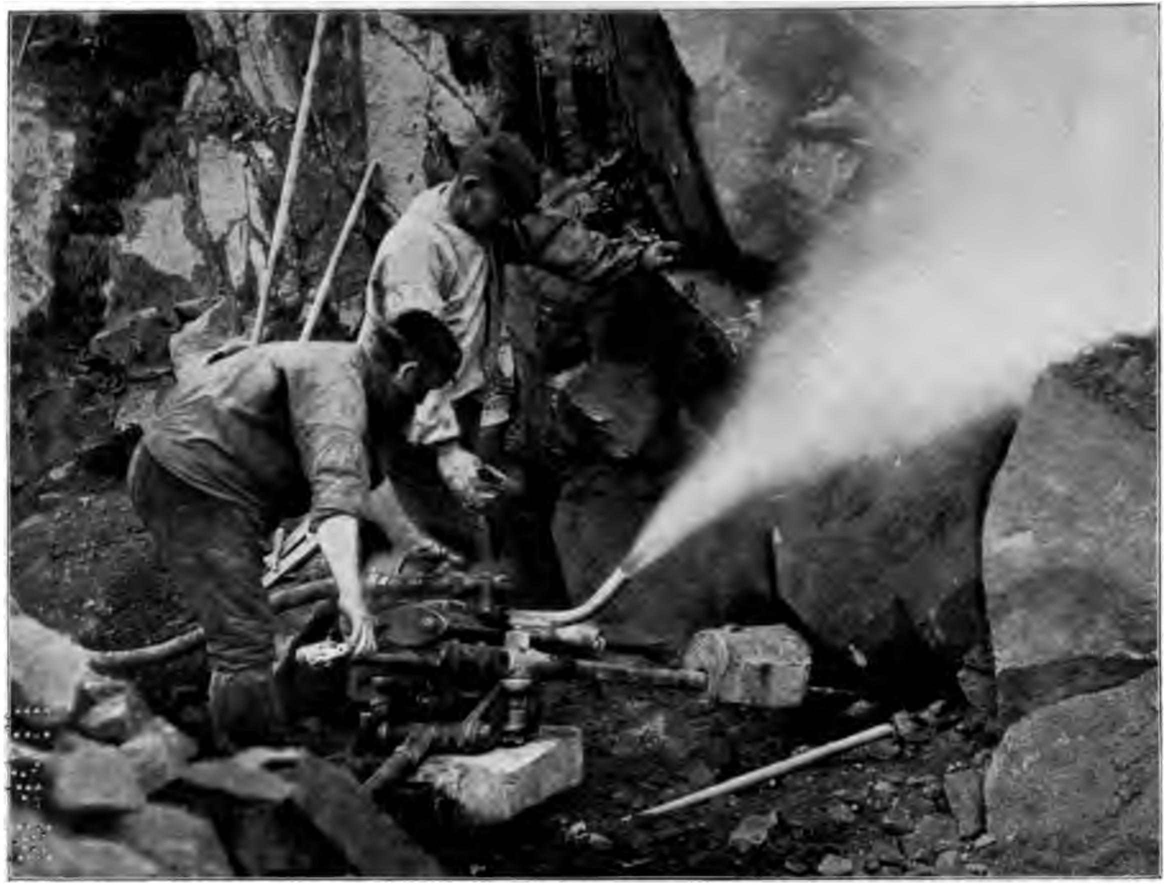

FIG. 71.—Machine drilling horizontal or breast bore-hole.

[*To face p.* 152.

an inch of the surface of the rock by means of the feed screw. As the rock is penetrated the stroke is lengthened, and the force of the blow increased so as to attain the full drilling capacity of the machine; the length of stroke varies in different rock drills, that of the 'Ingersoll-Sergeant' being from 6 to 7 inches.

In tappet-actuated valves the stroke may be shortened to about 4 inches by working on a cushion of steam or compressed air in the cylinder, the full stroke of the drill, the valve of which is operated by this means, being 7 inches. The variable stroke alone constitutes a very great advantage, and a rock drill possessing this property will start a bore-hole in half the time required by one working on a longer stroke. Again, a perfectly straight bore-hole is also easily made with a machine having a variable stroke. Another advantage possessed by a rock drill with a variable stroke is that the stroke can be shortened should a bit become accidentally fixed. Many of the different types of rock drills work at a pressure of 40 lbs. to the square inch, but the 'Ingersoll-Sergeant' drill, when working at a pressure of from 70 to 80 lbs. per square inch, will perform a greater amount of boring in proportion to the difference of the pressure stated. The oiling of the valves and piston is effected after the drill has been at work some little time, and when the condensed steam is got rid of, the oil being applied in small quantities at frequent intervals. The piston should be kept thoroughly lubricated, in order that the friction in the stuffing-box may be reduced to a minimum.

The feed or forward movement is regulated by the feed screw, and depends on the rapidity with which the cutting edge of the bit penetrates the rock.

It is essential to expeditious boring that the drill-bit, except in starting a bore-hole, should be fed just fast enough to give the piston its full stroke. When fed too slowly it will strike the front head, and if too fast, the useful effect of the cutting tool is reduced, and the power expended on the machine itself instead of on the rock. The depth to which a bore-hole should be drilled will depend greatly on the size of the rock drill employed and the class of work undertaken. For holes 20 feet deep, experience shows that the best results are obtained with a machine having a cylinder 3½ inches in diameter. The hole is commenced with a drill-bit having a cutting edge 3 inches wide, and is finished at the depth stated with a 1¾ inch bit.

For general handiness, where manual labour only is available for handling the machine, weight being an influencing factor for expeditious work, a drill having a cylinder diameter of 3¼ inches, and capable of boring holes to a depth of 14 or 18 feet, is to be recommended. With this size of machine a bore-hole is commenced with a diameter of 2½ inches, and finished at the depth of 14 feet with a drill-bit 1¾ inches across. This depth and diameter of bore-hole admits of a large mass of rock being easily dislodged by means of high-grade explosives and electric blasting.

The feed or forward movement of this class of drill is 24 inches, consequently with each succeeding length of steel there is an advance of two feet until the desired depth is reached. The condition which the cutting edge of the drill-bits will present after boring 2 feet will depend on the hardness of the rock, and on the care exercised in hardening and tempering them. In average whinstone, and even in granite, a drill-bit if properly dressed and tempered may be used a second time, and in many instances one drill-bit has been used in boring 6 feet,—that is, made use of three times before being returned to the smithy to be re-sharpened.

It is a remarkable fact that the wear of the cutting edge of a machine drill-bit working in hard rock will, for a given amount of boring, be only $\frac{1}{5}$ or $\frac{1}{6}$ that of a hand-boring bit. Keeping the bore-hole clear of the chippings is a matter requiring some attention, the actual amount of boring being increased at least 30 per cent. by using water in the bore-hole; this also serves the purpose of converting the dust into sludge, which can be readily removed by the 'scraper.' A much better and at the same time quicker appliance for removing the sludge, is the small pump shown in fig. 72, having a ball or catch valve working at the bottom end of the pump, which allows the liquid to be forced up the tube to a certain point, on the return of which the valve falls and retains the contents, which are then removed from the bore-hole. A piece of $\frac{1}{2}$-inch iron rod is attached to the pump and forms the handle; it should be of sufficient length to easily reach the bottom of the deepest bore-hole. The pumping is performed at each change of bit; it is necessary at times, however, to remove the steel and clean out the bore-hole before the drill-bit has penetrated the rock to its full length; but as this involves an unnecessary loss of time, such delay should be avoided by keeping up a good supply of water. When the débris formed by drilling is of a viscous nature and adheres to the steels, it may be advisable to direct a jet of steam through a small piece of piping inserted into the bore-hole and attached to the steam hose; this will effectually clean out the sludge when other means fail.

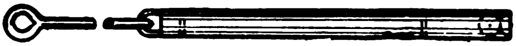

FIG. 72.—Bore-hole pump.

When the steel sticks in boring through seamy rock it may be relieved by striking it with a light hammer; but care must be exercised to deliver the blow on the stock of the drilling-bit, and not on the piston or chuck. If the rotating mechanism fails to operate after the drill-bit strikes a blow, the cause will invariably be a want of pressure on the washer at the back head of the machine. This can be quickly remedied by tightening the nuts of the side bolts, which will cause the back head springs to press firmly on the cap.

163. Work done by a Rock Drill.—The amount of work which can be accomplished by a rock drill in one day or in any given time, depends on the capacity of the machine itself, the nature of the rock to be bored, the manner in which the drill-bits are formed and tempered, and the size or diameter of the hole drilled.

In hard solid whinstone,* two feet may be penetrated in five minutes with a drill-bit having a cutting edge 2½ inches across. As each drill-bit has, however, to be replaced by a longer one for every two feet drilled, and the bore-hole also requires to be cleaned by pumping, some time must be allowed for this, say from three to four minutes for the combined operation. Starting with a drill-bit 2½ inches in diameter, a depth of 12 feet can usually be accomplished in an hour, including the time required for changing the bits and pumping out the bore-hole.

As the machine has to be changed from one point in the quarry to another as the boring proceeds, the actual time occupied in drilling is even less than this, especially when shallow bore-holes only are resorted to.

The actual work done in a day of nine hours will depend on the number of times the machine is changed from one point to another, and on whether the nature of the rock is solid or seamy. The time occupied in changing the machine and starting another bore-hole will depend to a certain extent on the distance to which the drill may have to be taken, and on the irregular nature of the rock surface. It is also contingent on the aptitude of the drill operator. The average time required is from 10 to 15 minutes.

It is obvious that when the machine has to be removed often during a day's work, the time so occupied will bear a considerable proportion to the time actually expended in drilling.

Taking all these circumstances into consideration, it will be evident that no criterion as to the capacity of a rock drill can be formed by simply putting it to work on a block of stone for a few minutes. A complicated machine might do good work in a short space of time, and yet be entirely useless in practical service. All those who are interested in quarrying operations should consider this matter carefully, and adopt those machines only that are made on proper principles, and are capable of withstanding the usage incidental to this class of work.

The actual amount of boring which can be performed in a given time either for comparison, or in order to determine the cost per lineal foot of hole drilled, can be arrived at only by averaging the day's work over a considerable period of time. In solid rock the author has, with an 'Ingersoll-Sergeant' drill, bored 70 feet of vertical holes in one day of ten hours; this is, however, too great an amount of work for every-day practice, as in boring through fissured rock, the actual performance may only amount to 35 feet, and even less in extreme cases.

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* This generic term applies to such rocks as andesite, basalt, dolerites, etc.

The experience gained in working this particular type of rock drill for a number of years, taking all classes of rock into consideration, and working under varying conditions, shows that the amount of boring which can be accomplished averages 42 feet per day of nine hours, each hole being of an average depth of from 10 to 14 feet, the cutting edge of bit used being 2½ inches across the mouth, and finishing at the bottom of a 14-feet bore-hole at 1¾ inches, or an average diameter of 2⅛ inches. In calculating the amount of work done, either by hand or by machine drills, it is advisable to follow some standard in determining the amount of drilling performed, so that a comparison may be made of the relative merits and drilling capacity of manual labour on the one hand, and of the different types of rock-drilling machines in use on the other. The cylindrical inch of hole bored, previously mentioned, affords a ready means to this end, and when applying this method in calculating the results of an average day's drilling, namely, 42 feet, it will be found that this amounts to 1071 cylindrical inches of hole bored, or 119 per hour. These figures include the time occupied in removing the machine from one point in the quarry to another, changing the steels, and pumping out the bore-holes. As already stated, a 12-feet hole may be drilled in one hour, including, of course, the necessary time for changing bits, etc.; this amounts to 315 cylindrical inches of hole bored in that time. From these results it is evident how essential it is to drill deep bore-holes, in order to avoid the delay occasioned by the repeated changing of the machine, during which time the drill is not working. In the event of bore-holes of shallow depth being adopted, as is sometimes done, it is very evident that changing the position of the machine repeatedly will occupy nearly as much time as the actual drilling, in which case the least possible advantages are attained by employing rock-drilling machines.

The means by which rock drills are actuated, as already mentioned, is compressed air or steam. In large quarries where boring operations are carried on during the greater part of the year, and probably employing a large number of drills, the most suitable and economical motive power is compressed air, which, besides these important considerations, serves as a means of preserving a clear atmosphere at the working face, and adds considerably to the best possible conditions for carrying on the operations.

In establishing a compressed air plant it is necessary to supply a compressor capable of providing a sufficient pressure for the number of rock drills which may be at work, the air being conveyed in pipes of relatively large diameter. By using compressed air as the motive power for rock drills, it is immaterial at what distance the compressor is situated from the point where the drilling operations are being carried on, as, provided there is no leakage, the pressure of the fluid working the drills is practically the same as at the compressor. In other words there is little or no loss of pressure between the point of compressing the air and that of using the compressed air.

In quarries where the work is carried on in an intermittent manner, such an expensive plant as has been described, while possessing many practical advantages, could not be economically employed. It is necessary, therefore, to make use of a boiler to generate steam for actuating the drill or drills. The most serious objection to the use of steam for this purpose is that at certain times of the year, owing to the humidity of the atmosphere, steam hangs about the working face, and greatly impedes the movements of the workmen.

A boiler generating steam, to be of any practicable use for such work, must be placed as near as possible to the point at which the drill is working, so that the steam may be had as dry as possible. If the distance between these two points be great, the steam in going through the long line of pipes becomes condensed, which, combined with the less effective pressure, places the working of the machine at a great disadvantage. This points to the necessity of the boiler being placed on wheels, so that it can be readily run from one point to another along the quarry face.

The pipes conveying steam as a motive power should be of as small diameter as is consistent with the work to be done, as the condensation on a large surface would be prejudicial to effective and economical working.

In quarrying rock for road purposes the usual, and, in fact, the only suitable way of providing the motive power is by means of a road or traction-engine, which, besides supplying the requisite steam for operating the drill, can be utilized for removing the drilling plant, and sleeping van for the use of the workmen, from quarry to quarry as occasion requires.

The connection with the boiler should be so placed that the steam for working the drill may be had as dry as possible. It is advisable when the drilling plant is once started in a quarry, although only a small quantity of material may be required, to drill a sufficient number of bore-holes which can be blasted from time to time as necessity arises. The reason for this is, that to change the plant from one quarry to another every day or second day increases the cost of drilling operations considerably, by reason of the time occupied in travelling between the different quarries. It will be apparent that the cost of drilling may be increased to twice what it should be by unnecessary changing from quarry to quarry, involving in some instances a whole day, before a sufficient amount of actual work can be performed in proportion to the time occupied. In other words, the time spent in travelling to a quarry for one day's drilling, which may be sufficient in order to produce the requisite quantity of material for immediate purposes, will involve an increase of cost compared with the same time and expenditure spread over a working period of from one to three weeks' duration.

164. Blasting.—In the foregoing pages the tools and machines used in rock boring, and the conditions necessary to be observed in placing the bore-holes, a matter of the highest importance, have been considered; it now remains to describe the methods adopted in charging and firing them, and the different kinds of explosives used for this particular class of work.

When it is advisable to simply rend the mass of rock so that blocks may be obtained as large as possible, it is necessary to make use of an explosive having a comparatively slow action. In the case of procuring material for road metal quite an opposite effect is desirable, pointing to the necessity of employing an explosive having an extremely rapid and violent action, which will shatter the mass of rock sufficiently, and obviate, as much as possible, the necessity of after manipulation.

In blasting rock from which dimension stones are to be produced, gunpowder is sometimes used; but special qualities of blasting powder are manufactured to suit the nature of the rock and the class of work for which it is intended.

Gunpowder as a Blasting Agent.—Gunpowder, the grains of which are small, is more rapid in action than coarse-grained powder; the explosion of the latter is adapted to simply rend and, by its slow moving and accumulative force, dislodge the mass of rock. Gunpowder is termed a direct explosive agent, that is, its force can be developed by direct means, such as ignition; it can also, however, be detonated by indirect means, which materially increases its explosive effect.

The composition of the blasting powder generally used in Great Britain is 75 per cent. saltpetre, 10 per cent. sulphur, and 15 per cent. charcoal. Dynamite of a low grade, or containing a small percentage of nitro-glycerine, may be adopted with advantage at times for blasting rock under the conditions mentioned.

High-grade Explosives.—The high explosive effect necessary to shatter the class of rocks used for macadamizing purposes, such as whinstone, is best obtained with high-grade nitro-glycerine compounds, fired by electricity. These high-grade explosives are termed *indirect* explosive agents, as they require an intermediary, such as a fulminate detonator, to cause them to explode properly.

The nitro-compound explosives of high grade are:—

Blasting gelatine No. 1,	which contains	94	per cent.	nitro-glycerine.
Gelatine-dynamite,	„	74	„	„
Gelignite,	„	63½	„	„
Dynamite No. 1,	„	75	„	„

Blasting gelatine is composed of collodion cotton, which is transformed into a jelly-like mass by being acted upon and dissolved by the nitro-glycerine.

Dynamite is composed of nitro-glycerine and a diatomaceous earth called

'Kieselguhr' or earth meal, found in some of the moors in Scotland and in Germany.

Blasting gelatine has an explosive energy 50 per cent. greater than No. 1 dynamite; but its action being slower, the effect is much less shattering. It is specially adapted for rending tough rock and dislodging it in large masses. Dynamite being a rapid and violent explosive, produces its effects very suddenly, and is therefore better adapted and fulfils the conditions necessary for supplying material for macadamizing purposes by dislodging and reducing the rock to a size which saves subsequent sledging; consequently the cost of quarrying is lessened.

If blasting powder is used in preference, or through some conservative idea that its effects are better in comparison with those of the nitro-glycerine explosives for a similar purpose, it is necessary either to make larger bore-holes or to increase the number, to obtain corresponding results.

It will be evident that in drilling bore-holes purposely to make use of blasting powder as the explosive agent, the cost of boring is unnecessarily increased.

From these observations it is obvious that the most economical results are obtained by drilling deep bore-holes with a rock drill, and employing high-grade explosives to dislodge the rock operated upon, so as to reduce it to suitable dimensions.

165. Different Explosives in relation to Wet Bore-holes.—In quarrying operations wet bore-holes have to be contended with, according to the position of the quarry and the season of the year in which the work is carried out. In such circumstances, blasting powder, unless in waterproof cartridges and used without stemming, is not permissible, as moisture detracts from, and in most cases destroys, its usefulness as an explosive agent.

Dynamite when retained in the parchment covering is not liable to be thus affected, but in 'pressing home' this explosive in a bore-hole the effect is to considerably alter the form of the cartridge, exposing the dynamite to the action of the water, when it exists. In charging the shot-holes under these conditions the nitro-glycerine exudes from the 'Kieselguhr,' which greatly impairs its explosive effect. In extreme cases where an accumulation of water in a bore-hole is such that the dynamite might be materially affected, it is advisable to use blasting gelatine, as this form of the nitro-compounds is practically unaffected by water.

The relative cost of the different kinds of the nitro-glycerine class of explosives may determine to a certain extent which of them should be employed in particular circumstances. Nobel states that dynamite is about six times, and blasting gelatine nine times, as strong as blasting-powder.

166. Conditions and Peculiarities of High-grade Explosives.—Dynamite may be 'too dry,' owing to a deficiency of nitro-glycerine in the absorbent; it may also be over-saturated, when the cartridges will feel greasy to the touch, which may be caused by storing the explosive in a badly ventilated place. In the former case the effect of detonation may only cause a partial explosion in the bore-hole, while the residue will simply burn away, and give off very foul gases. Dynamite, and the other nitro-glycerine explosives, should be in a plastic state when placed in the bore-holes; they have the disadvantage, however, of freezing at a comparatively high temperature—dynamite losing its plasticity at 40° F., while blasting gelatine becomes insensitive at a temperature of 45° F. It may take days to thoroughly thaw frozen dynamite, while, on the other hand, it may be exposed, when soft, for days to a temperature below 32° F. without losing its plastic condition.

Frozen dynamite requires a high initial detonation to explode it, and when in this state it is somewhat dangerous, owing, it is believed, to the breaking of the crystals causing some peculiar molecular action, which at times has brought about accidental explosions.

Special warming-pans are provided for thawing frozen dynamite, or even when it is in a slightly hard state; the process, however, is a slow one when large quantities of explosives have to be treated. The warming-pans consist of two galvanized zinc vessels, one inside the other, the interspace being filled with hot water and protected on the outside with felt to retain the heat. The frozen explosive is placed in the centre and covered with a lid; these warming-pans holding, according to size, from 2½ lbs. to 5 lbs. It is essential that the inside of the warming-pans be kept thoroughly clean, so as to reduce any possible chance of danger to a minimum. When repairs are necessary, the parts should be previously washed with a solution of 2 parts of caustic soda and 2 parts of alcohol to 96 parts of water, so that any nitro-glycerine which may be deposited in the crevices will be destroyed.

It is a difficult matter to keep the explosive which has been thawed in a thoroughly plastic condition, until the requisite quantity is so treated, previous to charging the bore-holes. Especially is this the case during cold weather in open quarry work, removed, as is usually the case, from any kind of shelter. A very speedy and effective method of thawing and keeping nitro-compounds in a plastic condition for immediate use may be carried out in the manner described in par. 167, and when ordinary care is exercised, little or no fear need be apprehended as to the results. It must, however, be remembered that these explosives detonate when heated above 356° F., and that chemical changes take place in dynamite above 158° F.

167. Warm stable manure is spread to a depth of one foot on the ground adjacent to the quarry where the blasting is to take place, and of a sufficient area to accommodate the quantity of explosive necessary, allowing a free space between the boxes. The boxes, containing 50 lbs. of explosive material, are then placed on this layer, and the lids partially opened, when a quantity of manure is spread over and between them, and allowed to remain until the explosive material is thoroughly thawed and in a plastic condition. Care should be exercised to avoid a high temperature, as already explained, for which purpose a thermometer may be advantageously applied at several points to ascertain the maximum heat, and, when necessary, the heat can be reduced by removing some of the manure.

168. Determining the Charge.—It is a somewhat difficult matter to calculate exactly the amount of explosive necessary to effect the purpose intended. The conditions may vary considerably at each bore-hole; the natural planes in many cases aid the operations; while when the nitro-glycerine explosives are used it is easier to blast seamy rock than a solid, tough mass of rock. The volume of material loosened may be taken as approximately proportional to the cube of the line of least resistance, which is generally the shortest distance from the charge to the surface of the rock; the proportion, however, varies in different cases, but may be roughly estimated at twice that cube. "In ordinary blasts the proportion of the weight of the rock loosened to that of powder used ranges from 4500 to 1 to nearly 13,000 to 1, and is on an average about 6000 to 1 or 7000 to 1. The ratio of the number of pounds of powder to the cube of the number of feet in the line of least resistance ranges from 1 to 32 to 1 to 10." *

Road-stone quarries generally permit of a systematically planned method of working being carried out, and especially is this the case in blasting the rock, although the amount of the charge cannot be determined with mathematical exactness. An approximate calculation can be made, however, sufficient for all practical purposes, with a view to fix the quantity of explosive necessary to loosen a mass of rock by proceeding in the following manner, a system which the author has adopted and made use of for years past with satisfactory results. The cubic contents or burden of the rock surrounding each of the bore-holes is calculated in relation to the adjacent ones, allowance being made of about one-fourth the depth of the bore-hole beyond its position towards the solid and also below the bottom of the hole as the probable boundary line where the available effect of the explosive ceases.

To illustrate this, let fig. 73 represent a quarry face about 30 feet long with three bore-holes placed as shown, 14 feet deep; the probable lines of fracture or crater are shown by dotted lines. Shot-hole No. 1 is situated 11 feet from the face and 10 feet from No. 2, and the free end towards *a c* is shown as 5 feet; therefore the contents of the mass of rock *a b*, *d c* (taking 17 feet as the probable depth which will be affected), represents (10 × 14 × 17) = 2380 cubic feet, which, allowing 13 cubic feet in the solid to each ton of rock, amounts to about 183 tons. The contents or burden surrounding the other shot-holes are calculated in a similar manner. Should the shot-holes be fired singly, the line of rupture will not follow the dotted lines *a b*, *d c* but may be approximately represented at *e*, *f*, *g*, when the quantity of rock dislodged may only amount to about 120 tons. If blasting powder is used, and the shot-holes are fired singly, experience demonstrates that 1 lb. of this explosive can move from 3 to 4 tons of rock, and in the case referred to a total quantity of 30 lbs. would be required in order that the charge should be strong enough to overcome the resistance presented by the cohesion of the rock. This is on the assumption that the bore-hole could contain this quantity of powder and admit of a sufficient amount of tamping being placed on the top, otherwise part of the charge would be blown out, diminishing its useful effect, and at the same time throwing the shattered rock at the mouth of the bore-hole in all directions.

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* Rankine's *Civil Engineering*.

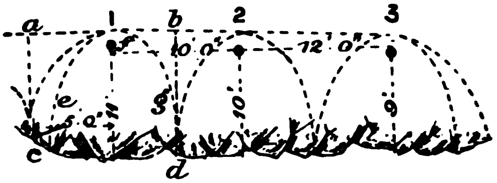


FIG. 78.

In the event of the shot-holes Nos. 1, 2, and 3 being fired simultaneously by electricity, then 1 lb. of blasting powder will throw down from 5 to 6 tons of rock, hence in the case of No. 1 hole rather more than 36 lbs. will be required to dislodge the mass *a b*, *d c*, or 183 tons of rock.

It is evident, therefore, that simultaneous blasting, even when using blasting powder, gives better results than when the shot-holes are fired singly. In very hard and tough rock the effect of blasting with blasting powder as an explosive agent is such that the mass of rock is simply dislodged; the large size of the blocks of stone resulting necessitates an additional expenditure to reduce them sufficiently, by means of plug-holes, for the purpose of sledging. This work is performed by boring a hole ¾ of an inch in diameter in the block, and about 1 or 2 feet deep, inserting powder, tamping, and firing the charge, so that it may be split in several directions, and reduced to pieces of a suitable size for sledging. This on an average requires from 5 to 10 lbs. of powder extra for each 100 tons of rock, and the inclusive cost of this drilling operation may amount to 2d. per ton quarried. This extra work, in addition to the mashing or sledging, which is an item involving considerable expenditure, will be explained in detail further on.

On the other hand, if dynamite containing 75 per cent. of nitro-glycerine is employed as the explosive agent, the quantity necessary to dislodge and effectually shatter the same mass of rock, *e*, *f*, *g* (fig. 73), would, firing the shot singly, amount to 12 lbs. In the event of all the shot-holes being fired simultaneously, which is the only economical method, then the quantity of dynamite necessary for shot-hole No. 1, allowing 13 to 14 tons of throw for each pound of explosive used, would be about 14 lbs. for the larger quantity of rock, namely, 183 tons.

In dimension-stone quarries, where the material is dislodged in large pieces, a considerable amount of work is entailed in reducing them by means of plug-holes and blasting. Formerly the plug-hole was usually made by hand-drilling, but the pneumatic hammer has been introduced for this purpose. This tool, which is an adaptation of Boyer's patent hammer for caulking boilers and chipping purposes, can make a plug-hole 1 inch diameter and 12 inches deep in three minutes. Undoubtedly the pneumatic hammer has a great future, as, besides being capable of boring holes, it can be applied for dressing the hardest rocks, which has long been a desideratum in the granite industry.

The relative strength of the two blasting agents mentioned has been ascertained by the 'ballistic' test, and experience shows that in the generality of cases the figures given may be relied upon when blasting any mass of rock, provided the conditions as to drilling the bore-holes have been observed. It is necessary, however, to carefully inspect the fissures and characteristic features of the rock, as the position of the bore-hole in a mass of rock may be to a certain extent locked or keyed, under which circumstances an additional quantity of explosive may be advantageously used. Blasting gelatine, as already stated, is about nine times stronger than blasting powder; but we may assume it to be only eight times as strong, as this figure harmonizes best with the results obtained in practice. Consequently, in firing the shot-holes simultaneously by electricity, the quantity of this explosive necessary for charging bore-hole No. 1 (fig. 73) would be about 5 lbs. The effects of blasting gelatine, however, are slower in action than dynamite, so that the mass would be brought down in large blocks, necessitating plug-holes and the employment of additional explosive to reduce the stones to suitable dimensions. Increasing the calculated quantity of blasting gelatine to, say, 8 or 9 lbs. would only have the effect of partially shattering the rock, while the mass would in all probability be thrown to a considerable distance, necessitating its being recovered and deposited at the quarry face. In extremely tight places in a quarry face blasting gelatine will burst and throw a mass of rock, while dynamite will only shatter it without dislodging it.

The same process is carried out in determining the charges for the other shot-holes, and although it occupies some time and is only approximately accurate, it is nevertheless an infinitely better method than that usually adopted of fixing the amount of explosive necessary to discharge a mass of rock 'by sight.' The latter method of fixing the quantity of explosive required, or, as it proves to be in most cases, guessing, is a 'rule-of-thumb' system of arriving at the desired results, for, in such cases, it is usually found that the quantity of explosive used was either too much or too little for the work to be done. Overcharging the shot-holes is a dangerous practice, and should be carefully guarded against in all quarrying operations.

169. The position and direction of the bore-holes in road-stone quarry No. 2, taken from actual practice, are shown in fig. 74, as also the quantity of explosive (dynamite) used and the depth of each shot-hole; for instance, in $\frac{10}{14}$ the lower figure indicates the depth of the bore-hole, the upper one the amount of charge in pounds, while the holes are indicated by the numerals 1, 2, 3, etc.

The quantity of explosive used in each shot-hole was determined by the method described; in the top holes 1 lb. of dynamite was allowed for dislodging 13 tons of rock, while in the bottom holes 1 lb. was allowed to every 10 tons of rock. The total quantity of material calculated as likely to be dislodged was 3400; but the actual quantity of rock quarried and passed over the steelyard was 3475 tons, so that on an average 12½ tons of rock was thrown or dislodged and broken up for each pound of explosive used. The appearance of the quarry face during drilling operations, and previous to blasting, is shown at fig. 92, while the result of the blasting, taken immediately after the shot-holes were fired, is represented in fig. 94.

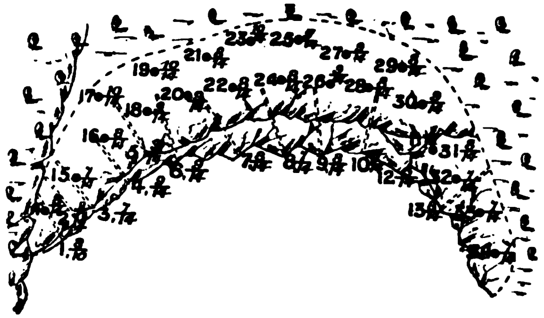


FIG. 74.—Road-stone quarry No. 2.

170. Another example of a road-stone quarry, No. 3, is shown in fig. 75; the position and direction of the bore-holes, and the quantity of explosive used in each, are represented in a manner similar to that described in the preceding paragraph; a cross-section, A A, and the quarry face are shown in fig. 76. In this case the quarry, although formerly in use, had never been blasted, the limited quantity of metalling required each season having been obtained from the loose material on the top by means of bars and wedges.

The rock consists of basalt of a very tough and stubborn nature; consequently it was considered advisable to place the bore-holes closer to each other than in the cases already referred to.

The amount of rock required for the purpose of forming a new road in the vicinity was 2000 tons, and considering the nature of the rock it was deemed advisable to work within a safe limit, the amount of the charge allowed being 1 lb. of explosive to every 10 tons of rock. The appearance of the quarry face previous to blasting is shown in fig. 95, and the result obtained is represented in fig. 96.

The actual quantity of rock dislodged and broken up suitable for sledging turned out, after weighing, to be 2102 tons, or equal to 10½ tons of throw for each pound of explosive used. The actual cost of drilling, charging, and blasting in these two quarries is given in detail on pp. 185 and 186.

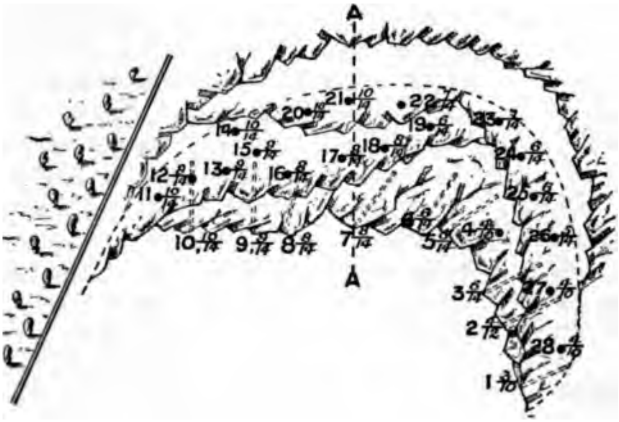


FIG. 75.—Road-stone quarry No. 3.

171. Charging the Shot-holes.—Before commencing the operation of charging the shot-holes, it is necessary to remove any sludge or water which may be in them by the means already described, in order that they may be rendered as dry and clean as possible. Moisture will cool the gases produced from the explosive when fired, and therefore a part of the energy is uselessly expended in evaporating it, while the action of some explosives is lessened or prevented by it. If blasting powder in a loose state is to be employed as the explosive agent, particular care should be exercised, for the reasons given. The bore-holes ought to be thoroughly wiped dry by means of a piece of tow or other suitable material attached to the eye of the scraper, which is passed slowly up and down the bore-hole to absorb the moisture.

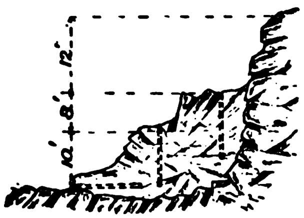


FIG. 76.—Cross-section at A A of road-stone quarry No. 3.

After determining the amount of the charge by the rule given, the requisite quantity is placed in the shot-hole; if the explosive is blasting powder in a loose state this is accomplished by means of a tin or copper tube, so as to prevent its coming in contact with the sides of the bore-hole. Blasting powder is also made up in cartridges having a waterproof covering, in which form it has many advantages. One pound of blasting powder in a loose state occupies about 30 cubic inches, and 27½ cubic inches when pressed, so that the quantity to be placed in a bore-hole can be determined exactly by measurement. Dynamite and the gelatinous explosives are made up in cartridges with paraffined paper wrappers, and are generally 3½ inches long and 1 inch in diameter for the former and ⅞ths of an inch for the latter. Boxes containing 50 lbs. are subdivided into ten cardboard boxes made up of 5 lbs. each. The number of sticks to a pound of the nitro-glycerine explosives can thus be easily ascertained, being generally eight or nine, and this at once is a measure to guide the foreman quarryman in charging the shot-holes.

The plastic nature of the nitro-compounds affords a great practical advantage in charging, as it admits of their being readily rammed home into the shot-hole, so as to fill all the seams and crevices. It is advisable, in order to save time when charging machine-drilled shot-holes, to place three sticks of explosive at a time into them, instead of singly; this is done by tying them together with a piece of twine previous to commencing the charging operations, the combined thickness being sufficient to fill the lower part of a 14-foot bore-hole. They are then dropped into the vertical holes, and pushed into the horizontal ones, to the required number, and thoroughly rammed home, each lot of three separately, by means of a tamping rod made of wood, without using undue force; the more compact the cartridges are, the greater will be the effect of the explosion. Care must be exercised in seamy rock, the bore-holes in which may be irregular or ragged, as in some instances 'bunching' of the explosive takes place. These conditions must be guarded against as being wasteful of explosive material, and the air space formed may cushion and detract from the force exerted in blasting.

If a charge of blasting powder is to be fired by means of a straw, a pointed metal rod of small diameter called a *pricker* is placed against the side of the bore-hole, with its lower or pointed end in the charge. The tamping is then proceeded with, which, considering the heaving tendency of blasting powder, requires not only that it should be of a dense nature, as, for instance, moist clay, but be firmly rammed. The pricker is then carefully withdrawn, leaving a circular passage through the tamping down to the charge. Into this passage the straw, properly filled with powder of fine grain, is inserted; the charge is then ready for firing. This method of firing charges, although defective and dangerous, was the method exclusively adopted years ago.

The firing of a powder charge is generally effected by means of a safety fuse, a piece of which, sufficiently long to reach from the top of the charge and to project a few inches above the bore-hole, is placed in a similar position to that occupied by the pricker in the case referred to, and the tamping proceeded with in a similar manner as described in the preceding paragraph. Better results will, however, be obtained if the fuse is placed in the centre of the charge so as to ensure its igniting and exploding properly.

It is a well-established fact that an electrical current will produce a more powerful initial impulse in firing shot-holes charged with powder than by the ordinary safety fuse; this method of blasting will be described presently.

In blasting with dynamite and the other nitro-compounds as the explosive, the firing cannot be effectively carried out by safety or any other kind of fuse alone. To bring about instantaneous decomposition in the nitroglycerine class of explosives it is necessary to produce in their midst an explosion of some other substance. This is effected by means of a detonator, or copper capsule containing fulminate of mercury.

A short piece of safety fuse with a clean-cut end is inserted into the open end of the detonator till it reaches the fulminate; the detonator is then pressed tightly round the fuse by the aid of a pair of pliers specially made for the purpose. The detonator is then pushed to a depth equal to two-thirds of its length into the primer, a hole being previously made in the primer by means of a small round piece of wood having a similar diameter to that of the cap or detonator, the paraffined paper wrapper is then laid over and secured to the fuse. To ensure proper detonation the safety fuse in the cap ought not to touch the dynamite primer, as, should this occur, the explosive may become ignited previous to the fulminate of mercury in the cap exploding, which, besides creating noxious fumes, would detract from its explosive effect. The method of fixing the fuse and the other details necessary are shown in fig. 77, *a* being the fuse, *b* the detonator, *c* the primer or cartridge of dynamite, and *d* where the paraffined paper wrapper is secured to the fuse by a piece of twine.

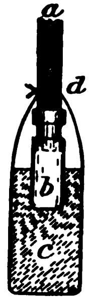


FIG. 77.—Dynamite primer and ordinary fuse.

When damp or wet bore-holes are encountered, it is advisable to smear the connection between the detonator and the fuse with tallow or some other kind of water-resisting composition.

It is a common practice to insert a paper wad on the top of the primer and detonator before the tamping is commenced; this forms a cushion and protects the detonator.

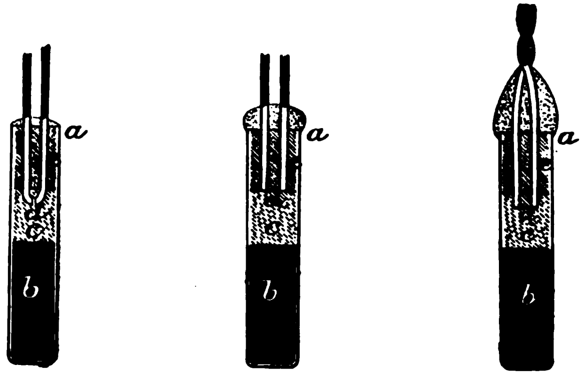
When a number of shot-holes are to be blasted simultaneously, the employment of electricity to fire the charge presents numerous and great advantages; even in single-shot firing it is much superior to the safety fuse and detonator by its producing a greater useful effect.

172. Electric Detonator Fuses.—These consist of a charge of explosive compound, usually fulminate of mercury, suitably placed in the circuit of an electric current, and acted upon in a manner and degree sufficient to produce an explosion. The mode in which the current of electricity is made to act depends on the source or manner in which it is generated, being either of high intensity but small in quantity, or of low tension and of great quantity.

Two kinds of electrical exploders are therefore manufactured, consisting of three types to suit these two different conditions or sources from which the electric current is produced. These three types are the *slot* detonator, fig. 78, the *bridge* detonator, fig. 79, and the *incandescent* detonator, fig. 80, but are commonly called tension and quantity detonators.

Slot Detonator.—The slot detonators are thin copper tubes—*a*, about ¼ inch in diameter, closed at one end and partially filled with a detonating composition, *b*, consisting of fulminate of mercury in varying quantities up to 2 grammes or 31 grains. On the top of this composition there is placed a layer of priming or flashing mixture, *c*, which is generally made of antimony sulphide and potassium chlorate. The wire for conveying the electric current is bent at the lower end in the form of the letter U, around which a plug, *e*, of melted sulphur and powdered glass is moulded, a fine slot being cut through the wire as shown at *d*. The plug is then inserted into the copper casing, so that the two bent ends of the wire project into the priming mixture; it is then made water-tight with india-rubber solution.

Bridge Detonator.—The bridge detonator is similar in form to the previous one; the wire terminals are, however, filed off flush with the inside face of the plug, along which and between the ends of the two wires a line is drawn with a soft black lead pencil. This forms a path for the electric current to pass along, with many points at which sparking takes place.



Slot. Bridge. Incandescent Detonator.

FIGS. 78, 79, 80.—Electric Fuses.

Incandescent Detonators.—The incandescent detonators are made in a similar manner to the slot type, but the ends of the wires are placed in the priming or flashing mixture and connected by a very fine platinum wire, *d*.

Owing to the great electrical resistance of the platinum wire, it becomes red-hot when a current is passed, thereby effecting the necessary explosion.

This type of exploder requires an electrical current of great quantity to explode it, but of low tension, while the slot type of detonator requires a high tension current to ignite it. Detonators contain a mixture of from 80 to 95 per cent. of fulminate of mercury and 20 to 5 per cent. of chlorate of potash, those for electric blasting generally containing 90 to 95 per cent. of the former and 10 to 5 per cent. of the latter. They are manufactured with charges varying from 8 to 31 grains; No. 6 detonator, or sextuple strength, containing 1 gramme or 15·4 grains, are those usually employed in quarry work for supplying macadam. Detonators of insufficient strength are a source of danger, and many accidents are traceable to explosives of the nitro-compound class being improperly exploded. It is essential, therefore, to employ those of a proper strength to ensure effective work; in many cases No. 8 detonators are employed, especially in very wet bore-holes; these contain a charge of 31 grains. The lowest standard for detonators required by the Home Office is 80 per cent. fulminate of mercury and 20 per cent. of chlorate of potash. Low tension electric detonator fuses remain, if properly stored, in good condition for an indefinite period; but high tension detonator fuses do not.

173. The detonators are inserted in the primers, whatever kind of nitro-compound explosive is used, by making a hole at one end by means of a small piece of round stick, thoroughly covering the exploder with the dynamite, and securing the paper wrapper to the wires by means of a piece of twine. It is then placed in the bore-hole and in contact with the charge, the wires being sufficiently long to reach at least a foot beyond the surface of the rock.

174. Some authorities on blasting claim, in order to properly fire a charge of dynamite or the gelatinous compounds, that the detonator should be placed in the centre of the charge, and that even two or three should be employed and distributed in the body of the charge to obtain, if possible, a higher initial explosion. This, no doubt, would have a beneficial effect in extremely deep shot-holes, and where the charge is an extended one of great length; but to properly charge and tamp a hole under such conditions is a matter of great difficulty, and the process is not wholly free from danger. It is desirable, however, when blasting rock which is likely to be dislodged in large blocks, to divide the charge; that is, first placing one-half the calculated quantity of explosive in the lower part of a bore-hole to fix the detonator in position, tamping material being added to a height of a few feet, then placing the remainder of the charge on the top of this, and repeating the process of fixing the detonator and tamping. When working with double charges the shot-hole wires must be properly joined with those on either side.

175. Tamping the Shot-hole.—The effective tamping of the shot-hole after the charge has been inserted is a matter of great importance, as the object is so to increase the resistance as to prevent the escape of the gases generated by the explosion in the direction of the bore-hole. The material employed must therefore possess great power of resistance, be of easy application, and be free from grit or other hard matter which would have a tendency to cut or damage the insulation of the wires in the shot-hole. Moist clay suits the first condition admirably, but its application in tamping the bore-hole occupies a considerable time. Sand satisfies the second condition, but even when compact, water permits of the gases being insinuated between its particles.

When blasting powder is used, a sufficiently deep and solid tamping is indispensable, and no time should be spared to make it thoroughly uniform and tight. The action of blasting powder when exploded has a lifting tendency; it should, therefore, be tamped entirely with clay in order that the full explosive effect may be directed on the rock to be dislodged.

When a charge is fired by detonation, the action being much quicker than with safety fuse, the tendency just mentioned is greatly diminished.

With the nitro-glycerine class of explosives sand alone is often used; the general effects of the blast, however, are considerably increased by employing a few pellets of clay in addition. With a powder charge it is usual to place a wad of paper or straw next the explosive before commencing tamping operations, and then slightly press the material until a safe height above the charge is attained, when it may be rammed. In tamping a dynamite charge it is usual to place some sand in the shot-hole directly on the detonator so as to cover it; a few pellets of moist clay are then gently pushed over this for a foot or two in depth, when the ordinary tamping material is scooped into the shot-hole and rammed with a wooden rod until the surface is reached. Care should be exercised to avoid a cushion of air between the explosive and the tamping material.

In either case the man who is deputed to do this work should hold the fuse or the wires of the electric exploder in his left hand while he works the tamping-rod with the other hand. The least movement of the fuse or wires caused by the tamping-rod coming in contact with them will be instantly felt; this enables the operator to avoid the rubbing, which is injurious to them. Apart from the possibility of cutting or destroying the covering or insulation, which in damp shot-holes might adversely affect the firing of them, the wires of the electrical exploders may be broken by incautious handling and thus rendered inoperative. For this reason the tamping-rod is sometimes made with a slanting instead of a square end, as shown in fig. 81. It will be seen that the point *a* will always have a tendency to rub hard on the rock face of the bore-hole farthest away from the fuse or wires, thus guarding against the least possible chance of damaging them. After the tamping-rod is placed in the bore-hole, however, it may be uncertain at which side the point *a* is situated. To obviate this difficulty it is advisable to run a groove diametrically opposite to the point *a* the whole length of the rod, then by observation it can be held in the position which will keep the point as clear of the fuse or wires as possible.

Tamping shot-holes charged with the nitro-compounds by means of water has many advocates and is extensively made use of, but in the author's experience such a method of tamping for road-stone purposes has not been attended with satisfactory results, and is certainly not to be compared in any way with the system of tamping described in the preceding paragraphs.

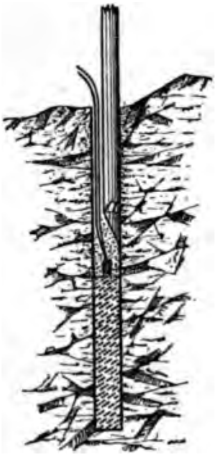


FIG. 81.—Tamping rod.

176. Nature of an Explosion of Nitro-Compounds.—It is generally believed, even by those of some experience, that the direction of impact of the nitro-compounds, when exploded, acts in a downward direction. This is not the case, however, as may be inferred by considering the following facts, which do not justify the general use of water as a means for tamping shot-holes.

If a cartridge of dynamite is suspended in mid-air, where the resistance around it is equal on all sides, it will, provided the explosive is of a uniform composition, and is detonated throughout its body simultaneously, cause the gases generated to expand equally in all directions. The only difference between the explosion of a charge of blasting powder and that of a dynamite cartridge is one of degree, the latter being much more quickly converted into a gaseous state; hence its action is rapid. If a cartridge of blasting gelatine or dynamite be placed on a block of stone and detonated, it is possible that under most circumstances the stone will be cracked in several directions. This does not prove, however, that the impact is entirely downwards, as only a limited amount of the explosive effect created may have acted in this direction by reason of its rapid action on the surface of the stone. A cartridge of the same kind and strength placed in the bore-hole of a block of stone of equal size and solidity and effectively tamped—in other words, similar to the one already operated upon—having equal resistance all round, would cause it to be shattered and the fragments would probably be thrown in all directions. It will thus be seen that, with an equal resistance, the gases generated by the explosion of dynamite will expand equally in every direction. Should the resistance be unequal, however, the explosive effect will be deflected in the direction of the line of least resistance. Hence in shot-holes tamped with water it sometimes happens that the deflected energy of the explosive follows the bore-hole, as it easily overcomes the resistance of the water, and expends its useful effect in the air. This explanation of the nature of an explosion of the nitro-compounds is amply borne out in practice. In carrying out some quarrying operations the author had occasion to make use of water tamping, not as a matter of expediency, but from necessity. Of twelve shot-holes which were fired simultaneously three simply discharged the explosive into the air and on the quarry face opposite, the result being devoid of any useful effect. Two of these bore-holes were in a horizontal position and one vertical; from the last mentioned a small piece of loose rock surrounding the mouth of the hole was projected to a considerable height, and subsequently fell within a few feet of its previous position in the quarry. In bore-holes generally (especially in those drilled in a vertical direction) when there is a continuous flow of water (as was the condition of things in the case mentioned), it is advisable to place a few pellets of clay over the charge and to fill the remaining portion of the hole with sand. This assists in confining the gases when expanding, and therefore increases the effective results. Similarly, if the full force of an explosion is deflected when an accidental explosion of the nitro-compounds takes place, distant objects may be damaged, while objects comparatively near in different directions may not be affected.

177. Connecting the Shot-hole Wires.—When shot-holes are to be exploded simultaneously, the wires from the electric detonator fuses require to be joined to those on either side and also to the cables leading to the blasting machine, so as to form a complete metallic circuit. When the wires from the shot-holes are not long enough to join those on either side, it is necessary to make use of connecting wire, which should be of the same quality as the detonator wires and of a similar diameter. These latter are made from $\frac{1}{64}$th to $\frac{1}{32}$nd of an inch in diameter, and are insulated with paraffined cotton wound double, or with gutta-percha or fibre composition. The mode of joining the wires is to cut off the insulated covering for about 3 inches from the end of each wire, and then twist them together firmly in a somewhat reverse fashion, as shown in fig. 82.

The bare ends should be scraped with a knife, as the contact surfaces must be clean, bright, and free from dirt or grease. These bare connections when the ground is wet should be protected by covering them with insulating tape; this is especially necessary when the explosion of the charge is effected by a blasting machine generating a high tension current.

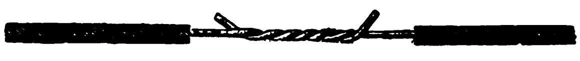


FIG. 82.—Method of connecting wires.

178. Circuits: different methods of connecting-up.—In effecting the metallic circuit between the shot-holes and the end of the cable wires, three different systems may be adopted in coupling-up the detonators, viz., (1) in series, (2) in parallel, or (3) in a manner combining both systems.

(1.) *Series Circuit.*—The method known as the *series* circuit, or connecting the wires in series, and shown in fig. 83, is the one most freqnently adopted when low tension or quantity detonators are used, which arrangement can be tested previous to firing. It affords a simple and effective means of forming the connections. Its only disadvantage is that a single defective detonator or faulty shot-hole wire will prevent all the others being fired, and cause what is termed a *misfire*; but by testing the exploders previous to inserting them in the shot-hole the risk of the defect mentioned may be reduced to a minimum.

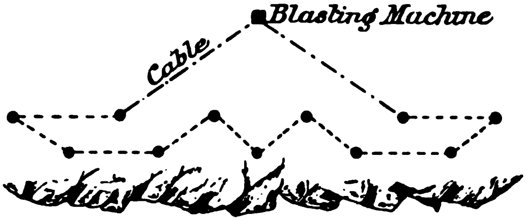


Fig. 83.—Connecting the shot-hole in series.

(2.) *Parallel Circuit.*—The mode of connecting the wires in parallel or direct circuit is shown in fig. 84; the wires of each shot-hole are in direct communication with the cables, and as they are independent of each other, they are free from the disadvantage incidental to the series method of forming the connections. The great amount of wire necessary to form the connection by this system, especially when there are a considerable number of shot-holes to be fired, increases the cost of the operations considerably.

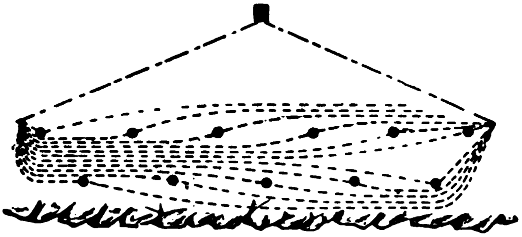


Fig. 84.—Connecting the shot-holes in parallel.

The connecting wires, instead of being placed so as to take the circuitous direction indicated in fig. 84, may be arranged in straight line between the shot-holes and the ends of the cable wire. They must, however, be kept entirely separate from each other in order to avoid complications, and the bare parts must be properly protected to ensure perfect insulation.

(3.) *Series and Parallel Circuit.*—The other method which may be adopted is a combination of the series and parallel circuits; this arrangement is shown at fig. 85. It will be observed that should a defective detonator exist in the front row of shot-holes *a b*, none of the others in that row can be fired; consequently, the back row of shot-holes, if they are in order, will be exploded. The force exerted, however, will not be sufficient to dislodge the rock in front, which, had the charges in all the shot-holes been exploded simultaneously, would have been effected.

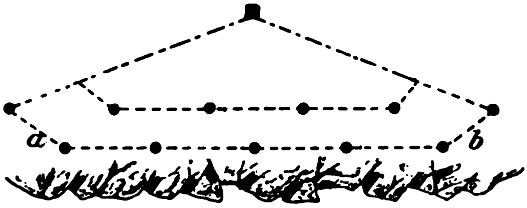


FIG. 85.—Connecting the shot-holes in series and parallel.

179. Connecting to Cables and Terminals of the Blasting Machine.—A wire from each of the detonators in the shot-holes nearest to the blasting machine is connected to the ends of the cable; and the other wire, as already explained, is connected to the next shot-hole wire when in series, and to the other cable when the parallel circuit is adopted.

The double cable is preferable for open quarry blasting; when high-tension detonators are employed the material of which the wires are composed is of little importance; it may be of iron. For low-tension detonators the leading wires or cables are made of copper, and of a comparatively large section, so as to admit of as small a line resistance to the current as possible. They are protected by gutta-percha or other suitable insulating composition, and for convenience in using and storing should be wound on a reel. This is a matter of some importance, as, when a cable is used without such an accessory, the time lost and the trouble occasioned by the wires becoming a tangled mass is very great, and result in the insulation being destroyed, and possible damage to the wires. As the blasting depends on a thoroughly efficient metallic circuit it is necessary, before using the cables in actual work, to test this by attaching them to the blasting machine and holding the free ends together, when, if they are in good order, a spark will appear on the current being sent through the cable wires.

180. Exploder or Blasting Machines. — Machines for exploding the detonators, and consequently detonating the charge in the bore-hole, are, as may be inferred, of two kinds. The blasting machine for firing tension detonators must be capable of producing a high tension or voltage, this being necessary to decompose the priming compound contained in the cap or detonator. The chief advantage of this class of blasting machine is the small effect of line resistance upon the current, in consequence of which the charges in the shot-holes may be situated at a relatively great distance from the blasting machine. As there is no possibility of testing high tension detonators except in actual blasting, it is usual to connect or couple up the shot-holes in parallel, so that each may be independent of the other; this minimises the trouble which may be experienced from a misfire should a faulty detonator happen to be in the circuit.

All the wires connecting the blasting machine and the detonators in the shot-holes must be perfectly insulated, however, as the smallest leakage of the electric current will greatly reduce the useful effect in blasting, and possibly lead to total failure. The high tension type of blasting machine is much employed in mines, and in single-shot firing; those principally used in this country are known as the 'Rackbar Exploder' (Smith's), and the 'Siemens' Exploder.' The Rackbar blasting machine, weighing 42 lbs., is capable of exploding simultaneously twenty-six high tension detonators in parallel. The Siemens' Exploder can only be used for firing high tension detonators, and is made of different sizes. The smallest size, 100 volts, weighs 8½ lbs., and can fire sixteen detonators, while the largest size, having four times that voltage, and weighing 21 lbs., can fire twenty-five high tension detonators.

For general quarry operations, however, the low tension system of blasting is in most favour, and possesses many points of great superiority compared with that of high tension 'exploders.' Low tension detonators possess the advantage that they can be tested, previous to being inserted in the shot-hole, by means of an electric galvanometer or by an electric fuse and blast tester. There is also the additional advantage that the whole charge can be tested by a weak current of electricity before connecting the leading wires to the blasting machine.

This testing machine is of great convenience, for, although detonators are now manufactured with great care, and seldom cause a misfire when proper care is exercised in handling them, still a detonator-testing machine is a valuable accessory to a blasting outfit, and its use may save considerable trouble and expense.

It is not of great importance that the wires for blasting on the low tension system should be thoroughly insulated, as bare wires are often used; but in damp places it is advisable to employ insulated wire, and to cover the joints or places where the connecting wires are coupled-up to avoid any possible escape of the electricity. The line resistance in connection with blasting machines generating a low tension current necessitates (as already mentioned) the employment of copper wire for the cables, which need not be of great length for ordinary quarry work. The length of the leading and connecting wires has a considerable influence on the total resistance in the circuit, consequently as this becomes greater the number of shot-holes which can be fired effectively will become less.

It is therefore usual to connect the shot-hole wires in series, because, as the detonators can be tested prior to the blasting taking place, there is but a small chance of a misfire. When the means of testing the detonators are not at hand the wires may be coupled-up in parallel, but of course a less number of shot-holes can then be fired simultaneously.

181. The principal blasting machines for firing low tension detonators used in this country are 'Siemens' Exploder,' 'Rackbar Exploder,' 'Crescent,' 'Pull-up Blasting Machine,' 'Victor,' and the 'Patent Dynamo Exploder.'

The Rackbar exploder or Smith's blasting machine, already mentioned, is extensively used in this country. It is a very serviceable machine, the largest size being capable of firing twenty-six high tension or thirty-five low tension detonators; it is of simple construction, and very effective when properly manipulated. The Crescent blasting machine is of strong construction, and although of considerable weight it is a very effective machine, being capable of firing thirty-five shot-holes simultaneously. This is the only electric blasting machine, so far as the author is aware, which discharges a uniform current of electricity on every occasion, no matter who may operate it. The 'Patent Dynamo Exploder' which has recently been introduced is operated by simply twisting a small handle quickly by about a half turn. The largest size weighs only 14½ lbs.; it has an E.M.F. of seventy volts and can ignite sixty charges. The low price is also in its favour. To obtain the best possible results with the other machines mentioned the operator must have had some previous experience, as it is possible to give a weak or a strong current at will, or by improper manipulation. Even those experienced have difficulty at times in operating these machines so as to discharge exactly the same quantity of current at each operation.

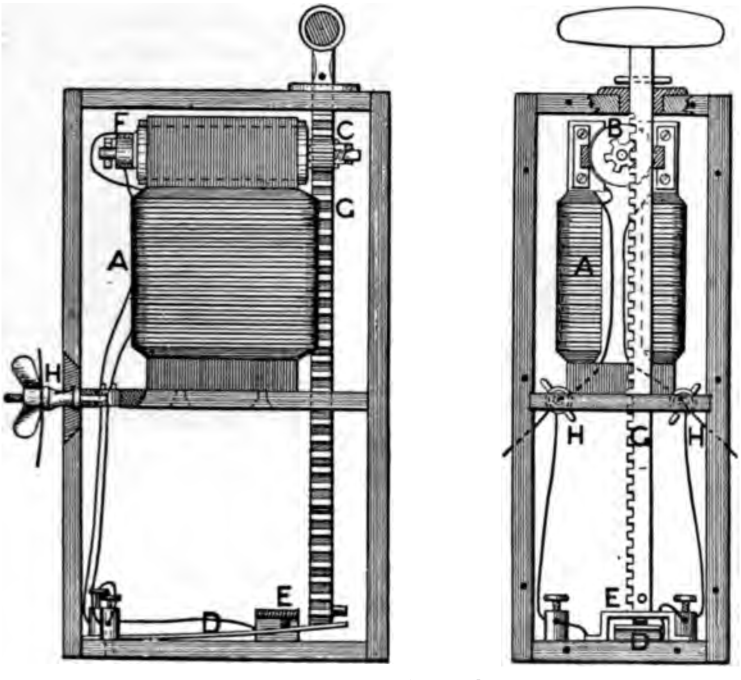
They all depend on the manner in which the electric current is generated, which is practically the same as in a dynamo.

Figs. 86, 87 illustrate the interior construction of a Smith's or Rackbar blasting machine, which for effective working compares favourably with any of the others, while the small size and moderate weight are greatly in its favour.

The iron magnet A is of the horse-shoe type, wound about with coils of insulated copper wire, and between the poles of the magnet there is a revolving cylindrical armature B, on the body of which insulated wire is coiled longitudinally. The rapid revolution of the armature generates and sustains in the machine an accumulative current of electricity of great power, which at the moment of its maximum intensity is switched off to the outside circuit, in which are the detonators. C is a loose pinion, its teeth engaging with the rackbar G, and, by a clutch, engaging with the spindle of the armature in the downward stroke of the rackbar. D is a spring which, when struck by the foot of the descending rackbar, breaks the contact between two small platinum bearings E, and causes the whole current of electricity to pass through the outside circuit. F is the commutator, while at H are shown the binding-posts or screws, to which the cables are attached. These machines are sometimes made with three terminals, namely, two out-current wires and one in-current or return cable. It is claimed that more effective work is performed by machines possessing this arrangement, but as yet few of them are in actual use.

Figs. 88, 89 (p. 178) illustrate the construction of the 'Pull Up' Exploder. It will be observed that the power necessary to generate the current is obtained by a series of toothed wheels which are geared approximately at 22 to 1.

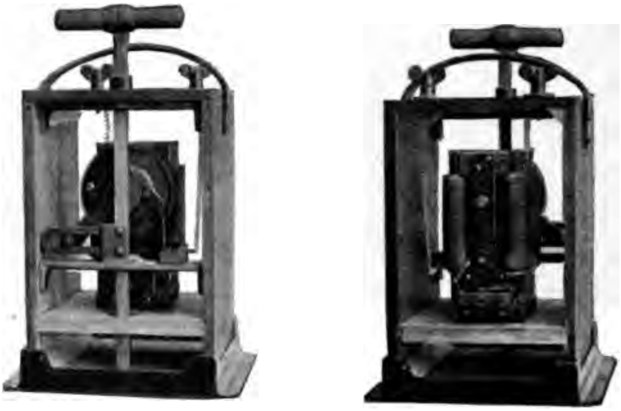
182. Final Arrangements for Blasting.—The final arrangement necessary to be made in carrying out the blasting is to place the machine at a safe distance from the quarry face, so that the operator and the machine itself will be out of reach of any pieces of rock which may accidentally be projected from the shot-holes when the charges are exploded. In most cases 100 to 150 yards is a safe distance, and provided the bore-holes are deep and the tamping is properly executed, there is little chance of any mishap occurring at this distance. In blasting, the rock operated on falls or is thrown in the direction of the least resistance, that is, from the rock mass towards the open portion of the quarry. The blasting machine, therefore, should be placed in a position opposite in direction to that in which a rock



FIGS. 86, 87.—Sections of 'Rackbar' blasting machine.

mass is expected to fall, so as to ensure its being placed in the least exposed situation. It is always necessary to bear in mind that from some cause or other a few detached pieces of rock may be projected upwards in an inclined direction ; therefore, when consistent with the preceding observations, it is advisable to locate the position of the blasting machine so that the operator's view of the quarry will not be interrupted by the sun's rays.

The cables are then connected to the binding-posts or thumb-screws of the blasting machine, the workmen are ordered to retire to a place of safety, everything is made ready, and the customary signals are exchanged. The handle or rackbar is then put in operation and the requisite electrical current generated, which is switched off into the circuit, when, if everything is in proper order, a simultaneous explosion will be the result, accompanied by a low rumbling noise which indicates effective work.



FIGS. 88, 89.—'Pull Up' blasting machine.

183. The instantaneous fuses or volley-firers made by the firm of Beckford, Smith & Co., of Tuckingmill, which are claimed to act simultaneously, differ from this firm's ordinary safety fuse in having a core of cotton wick which has been drawn through a paste of meal powder, instead of a powder train. When it is desired to fire several shots by means of this fuse, the required number are inserted into a tin socket or volley-firer, at one end of which is a plug of wood perforated to receive the time-fuse for igniting the instantaneous fuses leading to the shot-holes, and all the shot-hole fuses are concentrated in the receptacle and brought into contact with the disc. A gunpowder disc is placed against the plug, the whole being insulated with gutta-percha. The instantaneous fuse burns at the rate of 50 yards per second, and for open quarry work the T-pattern of volley-firer is generally made use of when the fuse is of any length. These fuses have to be specially made when the number of the shots and the distance apart is great, which particulars must be ascertained previous to the blast taking place. As a matter of convenience, they are generally made up and connected by the makers at their works.

This method of firing may be approximately simultaneous for a few shot-holes, but when a large number are intended to be ignited at once, the varying lengths of the patent fuse must necessarily mean a difference of time, and although to all appearance the explosion is simultaneous, it is evident that a few seconds must elapse between the actual explosion of several of the charges. With electrical firing this is not so, as the current must pass from the blasting machine through the outer circuit and return to it again before all the detonators can be exploded.

184. Misfires.—Should a misfire occur, it may be due to (1) a defective detonator, (2) faulty shot-hole wires, (3) the weakness of the current generated by the blasting machine. The first two causes should not occur in low tension blasting, as they are discoverable by testing previous to firing. The best way of guarding against the third cause is not to connect more shot-holes than the machine will fire with certainty.

The manner in which a misfired shot-hole may be relieved, an operation not wholly free from danger, is to remove a small quantity of the tamping, insert another one or two detonators, re-tamp with clay, and fire in the ordinary manner. The vibration or detonation of the newly inserted detonators gives rise to a sharp shock, which sometimes explodes the charge.

Should this means fail, and should it be absolutely necessary to explode the charge, then the tamping must be extracted, a process requiring great caution, perseverance, and time. When the tamping forming the cushion on the top of the explosive is reached, another detonator is inserted and the shot-hole re-tamped; on the charge being connected, it will in all probability be exploded. Another method of attaining the same object is to drill another bore-hole a few feet distant from the misfired one, and to a depth which will nearly reach the level of the top of the explosive in the hole which has failed to go off. This new bore-hole is then charged and fired, the loose rock carefully removed until the charge in the misfired shot-hole is reached, when by inserting another detonator and connecting the wires to the blasting machine, the charge can be fired.

When a bore-hole charged with blasting powder fails to explode, the cause may be traced to some inherent defect in the fuse itself, or to its having been damaged during tamping operations. The only means of rectifying this is to remove the tamping material, and to apply another piece of fuse, whereby the ignition and explosion of the charge will in all probability be effected.

185. Recording Charging Operations.—It is obviously most essential in quarrying operations to record reliable data respecting the charging of the bore-holes. The depth from the surface of the rock to the top of the explosive in any particular bore-hole being known, the preceding operations in connection with a misfired shot-hole are possible, but when such information is wanting, it adds considerably to the difficulty, and may be the means of introducing an unnecessary element of danger during the operations.

186. General Deductions.—The following observations will indicate the superior economy and safety of machine-drilling, combined with electrically fired high-grade explosives, over the old method of blasting powder ignited by safety fuses, which is still in use in many localities.

Deep holes tend to economy in drilling, if properly placed as regards position and direction, while the charges of the explosives when proportioned to the rock to be dislodged ensure useful work being accomplished.

The method usually followed of simply guessing what amount of explosive should be used to loosen a piece of rock, is wasteful in most cases, while the results obtained are variable and generally unsatisfactory. It may happen that an insufficient charge is made use of, dislodging the mass of rock in large blocks; this necessitates a considerable amount of additional labour, in order that they may be reduced to a proper size. On the other hand, an excessive amount of explosive may be placed in the shot-hole, which will reduce the mass of rock to such a size as to entail considerable loss, owing to its being unnecessarily shattered. Another result of overcharging, and which happens in the majority of such cases, is brought about by the gases expanding, and (owing to the small resistance offered) throwing the shattered rock in all directions, even beyond the limits of the quarry. This necessitates its being collected and removed, and adds to the cost of the operations. It will be obvious from these observations that in order to properly estimate the amount of explosive necessary for dislodging a mass of rock it is essential to observe the directions of the fissures and determine the approximate charge from actual measurement of the cubical contents of the mass of rock to be dislodged. The methodical procedure of the experienced blaster always conduces to economy.

The simultaneous firing of the shot-holes reduces the total amount of work necessary, a less number being required; and, as compared with single-shot firing, there is a corresponding reduction in the quantity of explosive for a given quantity of rock to be dislodged, which means a great saving of expense.

Vertical holes should always be put down when possible, as the amount of explosive necessary to break up the rock into suitable pieces is considerably less for vertical than for bottom or breast bore-holes. When a quarry face is of considerable height, it will be more economical to work it in benches or terraces, varying from 15 to 20 feet deep and 12 to 16 feet wide, and by drilling vertical bore-holes.

There is no such thing as 'hanging fire' when an electrical current is used as a means for firing the charges. If the shot-holes do not go off when the blasting machine is operated, the men can at once approach the quarry face with absolute safety, the only precaution necessary to be observed being to disconnect one of the cable wires in certain blasting machines, or to remove the handle, which should be retained by the operator. This precaution, during the temporary absence of the man in charge, prevents the machine being tampered with and a possible accident, which is, however, a very remote contingency.

With safety fuse it is otherwise, as almost all the accidents in connection with such blasting operations are brought about by their proving defective in some way or other. This fault may cause the fuse to 'hang fire,' and the workmen, probably after waiting for ten or fifteen minutes, approach the quarry face, when without warning, as has happened times without number, the charge explodes and the result may terminate fatally for those in close proximity. It requires but little reflection to understand that blasting by means of electricity is highly conducive to the safety of the men employed, which is a feature in itself sufficiently important to make its application universal. When a large number of shot-holes are fired with safety fuse, and the contingency of misfires almost inseparable from this method of blasting is considered, it will be obvious that an excessive amount of time is lost each day. In quarries from which large quantities of material are turned out, the time thus lost would be entirely obviated by electrically blasting the rock.

The method by which the bore-holes are drilled, the shot-holes charged and tamped, and the blasting carried out, having been fully described, it now remains, so far as these operations are concerned, to ascertain what the cost of quarrying amounts to per ton of rock dislodged. The tirring or stripping may vary considerably, and the price for this work per ton of rock quarried will depend on the height of the quarry face in relation to that of the depth of tirr or overburden removed.

TABLE XVIII.

Cost of working rock drill per day of nine hours.

Engine or boiler for generating steam, and attendant (hired), 11s.; coals, 6 cwt. at 12s. per ton = 3s. 7d., .	£0	14	7
Drill-runner, 4s. 2d.; assistant, 3s. 6d., ...	0	7	8
Dressing and tempering drill-bits, 4d. to 6d., according to their condition, each drill-bit boring on an average 4 feet before it requires to be dressed, ...	0	4	5
Oil and waste for drill only, ...	0	0	3
Team work, carting coals and water for engine, and the drill-bits to and from the smithy, proportion of day's work, ...	0	7	0
[*] Repairs, depreciation, and tools, allow, ...	0	0	6
Total, . . .	£1	14	5

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[*] Renewals and repairs, exclusive of drill-bits, have cost on an average 10s. each season during twelve years' use.

187. **Cost of Working Rock Drills.**—The author has found from experience, taking the work performed by a rock drill when boring from 35 to 42 feet of 2½-inch holes each day, that the rock after blasting and weighing averages from 250 to 300 tons. In other words, each 14-foot bore-hole, when blasted, produces about 100 tons of rock. From these data it can be easily ascertained what the cost of drilling amounts to, and from these figures the price per ton of rock quarried may be deduced.

Tirring or stripping may be taken at 0·68d. per ton of rock quarried.

Taking the amount of rock produced, after blasting, as 250 tons for each day's work, it will be found that the drilling operations cost 1·65d. per ton. If the quantity be taken at 300 tons for a day's work, then the cost for drilling will be 1·38d. per ton. Each foot of bore-hole drilled, taking 35 feet as a day's work and the working expenses as above stated, is found to be 11·80d., or nearly one shilling; while if 42 feet per day is taken, it equals 9·83d. per foot of hole of the diameter stated.

In quarries where drilling operations are carried on nearly every day during the year, the cost of providing the motive power may be considerably reduced. The team work is dispensed with when the supply of water is conveniently near, while the proximity of a smithy further tends to reduce working expenses; but these items of expenditure are inseparable from the operations carried on under the conditions mentioned in the preceding paragraphs.

A smith who has some experience in dressing and tempering drill-bits will perform the work more expeditiously, and the results will be better than where the work is done by one only occasionally employed in this class of work. The price for dressing a drill-bit under the circumstances mentioned need not exceed 4d. each, provided they are only moderately dulled, but it may be 6d. if the drill-bit requires more labour to bring it into proper shape.

188. The cost of explosives varies according to the class made use of, but taking dynamite containing 75 per cent. of nitro-glycerine as that used in charging the bore-holes, the price, when obtained in small quantities for blasting one quarry, and where it is intended to dislodge about 1000 tons of rock, may be as much as 1s. 3d. per lb.

The conveying of the explosive from some local magazine to the quarry where it is to be used, and thawing it when frozen, will increase the price by at least one penny before it can be placed in the bore-hole, and bring the total cost to 1s. 4d. per lb.

Dynamite, and indeed all explosives, when purchased in large quantities of say 1000 lbs. and upwards, can be obtained at considerably less cost, in some cases to the extent of 35 per cent. Economy and convenience will therefore be secured by having a suitable store or stores situated centrally in the district, from which the different quarries can be supplied. A description and drawings of a mixed store for this purpose will be found at the end of this chapter. By having a store for keeping the explosives required, the dynamite of the grade mentioned can be purchased, when taken in large quantities, for about 9½d. per lb. delivered at the store. When the building is situated centrally the cost of conveying the explosive is reduced considerably, and an allowance of one halfpenny per lb. will cover the outlay for this, and for any additional handling. The price of No. 1 dynamite and the gelatine explosives varies considerably from time to time; the former can be purchased at the present time* in quantities of from 800 to 1000 lbs. at 6d. per lb.

189. One pound of this grade of dynamite, as has already been pointed out, will throw and break up 14 tons of rock when the shot-holes are fired simultaneously by electricity; but allowing 12 tons of rock to each pound of explosive used, the cost will thus be 0·84d., taking the price of dynamite at 10d. per lb. for each ton of rock dislodged.

190. The cost of the electric detonator fuses, containing a charge of about 15 grains and having shot-hole wires 10 feet long, including connecting wire (which can be used again if not destroyed during the blasting operations), may be taken at 2d. for each shot-hole, or 0·02d. per ton of rock dislodged. The time occupied in charging the shot-holes, fixing the detonators in the primers, tamping and connecting the shot-hole wires, varies considerably. If the bore-holes are in solid rock, little trouble will be experienced in carrying out these different operations; in seamy rock, however, the time necessary to carefully and properly perform the charging and tamping will be greatly increased. Taking an average, experience shows that the whole operation occupies four men (two pumping out the bore-holes and conveying the explosive to the other two men charging) one hour for every 40 lbs. of explosive stemmed in the bore-hole, ready for blasting, including all the other necessary work involved. Five shot-holes can, on an average, be completed in an hour; so that, allowing for coupling-up the connecting wires and cables, an inclusive sum of 4½d. to 5d. may be taken as representing the cost for this work for each bore-hole. This is equal to 0·06d. per ton of rock.

191. Sledging the Rock for Hand or Machine Breaking.—The last operation consists of mashing or sledging the larger pieces of rock small enough to suit the hand-breakers for producing road metal or for a breaking machine, the general size being about 16 inches by 9 inches. The price per ton for this work depends upon the ease with which the rock can be broken. The quantity of rock of a siliceous nature which one man can sledge in a day of nine hours, including a large proportion of rock already small enough, is on an average about 22 tons; so that the cost would be 2½d. per ton quarried. Should the rock be of a very tough nature, and especially if it is in large blocks, the yield per day may only amount to 14 tons.

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* January 1907.

An average of these quantities, namely, 18 tons, fairly represents an ordinary day's work by one man. When vertical bore-holes alone are drilled, the cost of sledging is materially reduced, by reason of the mass of rock falling to the quarry floor being broken into smaller blocks.

The cost of sledging, therefore, allowing 4s. 1½d. per day for each man engaged in this work, and including an allowance for tools and repairs, amounts to 2·75d. per ton.

192. All the items summarized for the different operations involved in quarrying the rock to a size suitable for a 16 inches by 9 inches stone-breaking machine are as follows:—

TABLE XIX.

Cost of quarrying rock per ton, including mashing or sledging.

	Pence per ton.
Tirring or stripping, ...	0·68
Drilling, including repairs and depreciation, ...	1·65
Explosives, ...	0·84
Detonators and connecting wire, ...	0·02
Time occupied in charging the shot-holes, fixing the detonators, tamping, connecting the shot-hole wires, arranging the cables, etc., ...	0·06
Mashing or sledging, ...	2·75
Cost per ton, . .	6·00

From this summary it is apparent that the cost of sledging is relatively high compared with that of explosives. The great object to be attained is the use of just a sufficient amount of explosive so as to save after-manipulation, but at the same time overcharging the bore-holes should be avoided, which, besides scattering the rock about, reduces it in many instances to a size too small for the purpose intended.

In quarries where 'sets' of stone-breaking machines are used it is usual to have one at least of these, generally known as a reducing machine, working in connection with two or more ordinary macadam breakers. Under these conditions the cost of sledging is considerably reduced, as the rock does not require to be broken up to the size mentioned, and it may happen in some instances that the cost for this item disappears altogether.

193. Actual Cost of Quarrying in Road-stone Quarries.—Referring now to the results obtained in every-day practice, the following particulars are given for three different quarries from which material is taken for macadamizing purposes:—

Road-stone quarry No. 1.

Fig. 68, p. 151, shows the position and direction of the bore-holes, the height of the quarry face being 27 feet at one end and 40 feet at the other

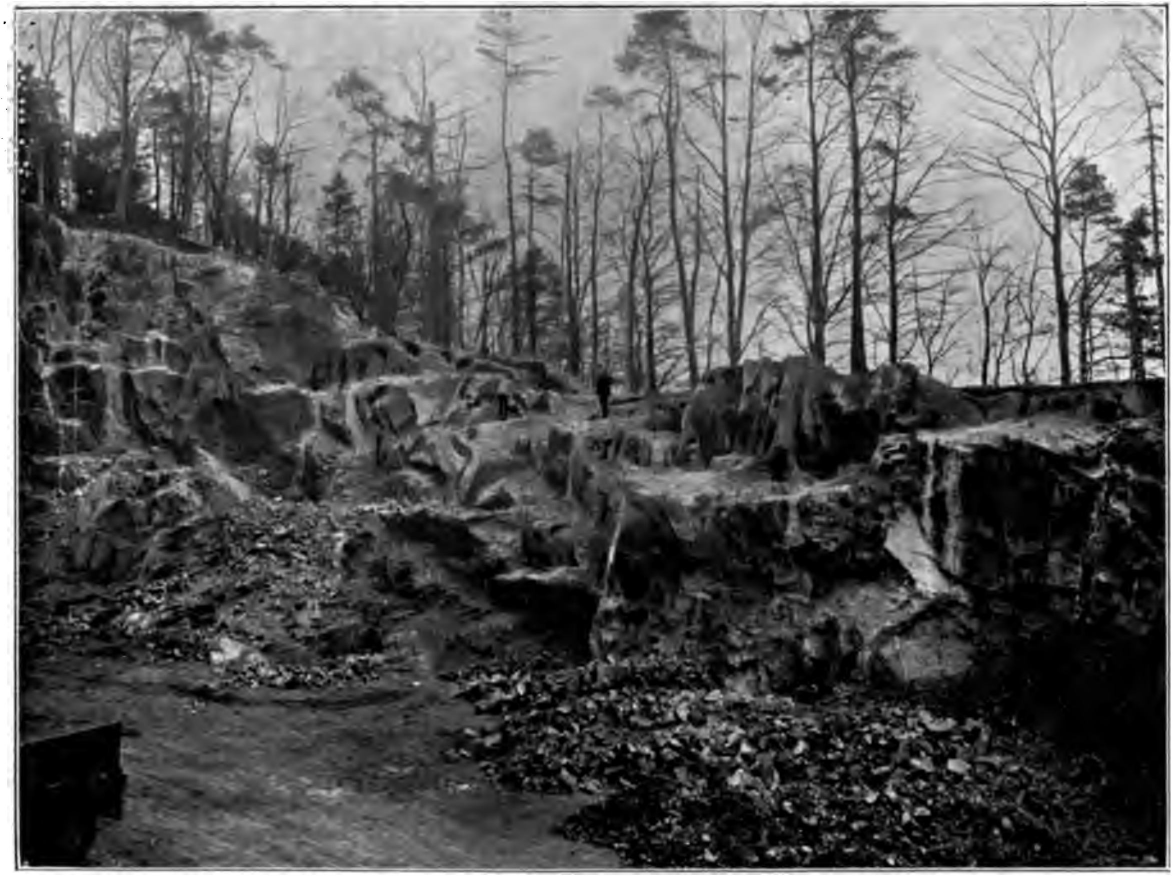

FIG. 90.—Road-stone quarry No. 1, showing face of quarry—charging shot holes. [*To face p.* 185.

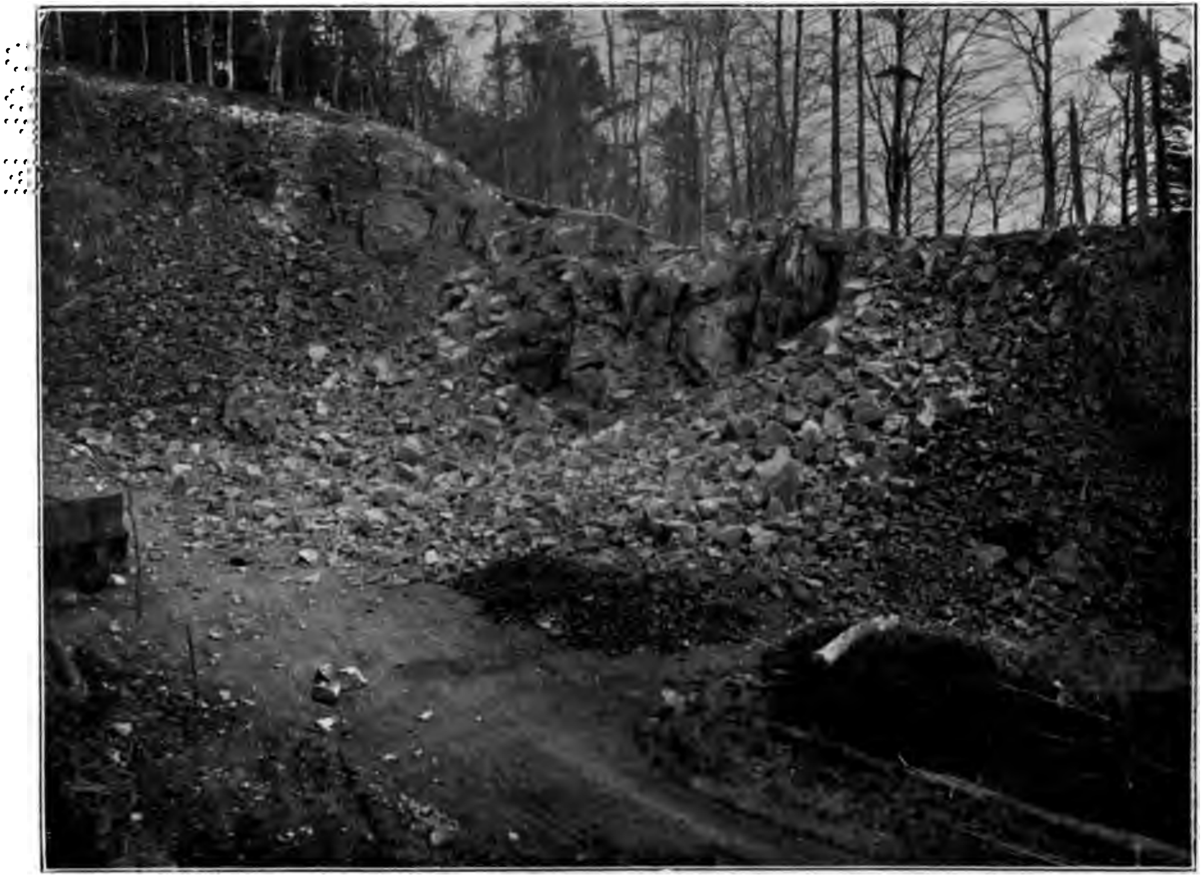

Fig. 91.—Road-stone quarry No. 1, showing result of blasting operations. [*To face p.* 185.

end. The rock (andesite) is of a hard nature and very seamy in parts, while about 60 per cent. of the total amount of rock quarried is of a very hard and solid nature. The quantity of material required was 4000 tons. Figs. 90 and 91 show this quarry previous to and after blasting operations respectively.

The total cost of tirring, drilling, etc., is given in detail in Table XX., and the relative cost of each item is also shown, the actual amount of rock quarried being 4158 tons.

Table XX.

Actual Cost of quarrying in road-stone quarry No. 1, including sledging.

	Working Expenses.				Cost per Ton Quarried.
Tirring or stripping,	£35	11	1		2·05
Drilling, including traction-engine for generating steam (hired), coals, water, dressing drill-bits, depreciation of drill, etc.,	30	11	3		1·77
Blasting—explosive (dynamite), detonators, supplying and coupling-up the wires, and time occupied in charging and tamping the shot-holes,	16	5	9		0·94
Sledging,	47	9	4		2·74
Total cost,	£129	17	5	or	7·50d. per ton.

This is at the rate of 7½d. per ton of rock reduced to a suitable size ready to be wheeled on to the platform of the stone-breaking machine.

It will be observed that the stripping is relatively high. This was brought about by the earth having to be shot over the face of the rock and carted a distance of over 100 yards. A considerable number of trees had also to be removed, the expenditure incurred being included in this item. The cost of the drilling operations includes the boring of breast-holes working from a staging; three days were lost owing to rain-storms, the quarry being in a very exposed situation.

Road-stone quarry No. 2.

194. Fig. 74, p. 164, shows the position and direction of the bore-holes, the average height of the quarry face being about 22 feet. The rock (andesite) is of a hard and tough nature, and although seamy in places, it is of a fairly solid character. The quantity of material required was 3400 tons.

The total expenditure incurred in this quarry is tabulated similarly to that of the previous case, Table XXI., the actual amount of rock quarried being 3475 tons.

TABLE XXI.

Actual Cost of quarrying in road-stone quarry No. 2, including sledging.

	Working Expenses.		Cost per Ton Quarried.
Tirring or stripping, ...	£10 0 0		0·69
Drilling, including engine (road roller), coals, water, dressing drill-bits, depreciation, etc., ...	19 5 0		1·33
Blasting — explosive (dynamite), detonators, supplying and coupling-up the wires, and time occupied in charging and tamping the shot-holes, . .	15 1 8		1·05
Sledging, ...	39 0 0		2·69
Total cost, . .	£83 6 8	or	5·76d. per ton.

The tirr in this quarry was deposited about 25 yards from the working face by means of wheelbarrows. The cost of the drilling is under that of the previous case, which is accounted for by the motive power for the rock drill being supplied by one of the road authorities' steam road-rollers; the expenditure, however, includes a sum for depreciation of the engine.

The appearance of this quarry during drilling operations is shown at fig. 92, and the appearance of the quarry face during the blast is depicted in fig. 93, while the effects of the blasting operations, which show an excellent result, are represented in fig. 94.

Road-stone quarry No. 3.

195. Fig. 75, p. 165, shows the manner in which the bore-holes were placed; a cross-section (fig. 76) is also given, showing the general outline of the quarry face. The rock in this quarry is a hard and very tough basalt, and of a very solid nature. The amount of material required was 2000 tons, and the expenditure incurred for the quarrying operations is detailed in same way as that in the previous cases, Table XXII. The total quantity of rock quarried turned out to be 2102 tons.

TABLE XXII.

Actual Cost of quarrying in road-stone quarry No. 3, including sledging.

	Working Expenses.		Cost per Ton Quarried.
Tirring or stripping, ...	£4 7 7		0·50
Drilling, including engine (hired), coals, water, dressing drill-bits, depreciation of drill, etc., ...	14 4 6		1·62
Blasting — explosive (dynamite), detonators, supplying and coupling-up connecting wires, and time occupied in charging and tamping the shot-holes, .	10 2 9		1·16
Sledging, ...	28 9 3		3·25
Total cost, . . .	£57 4 1	or	6·53d. per ton.

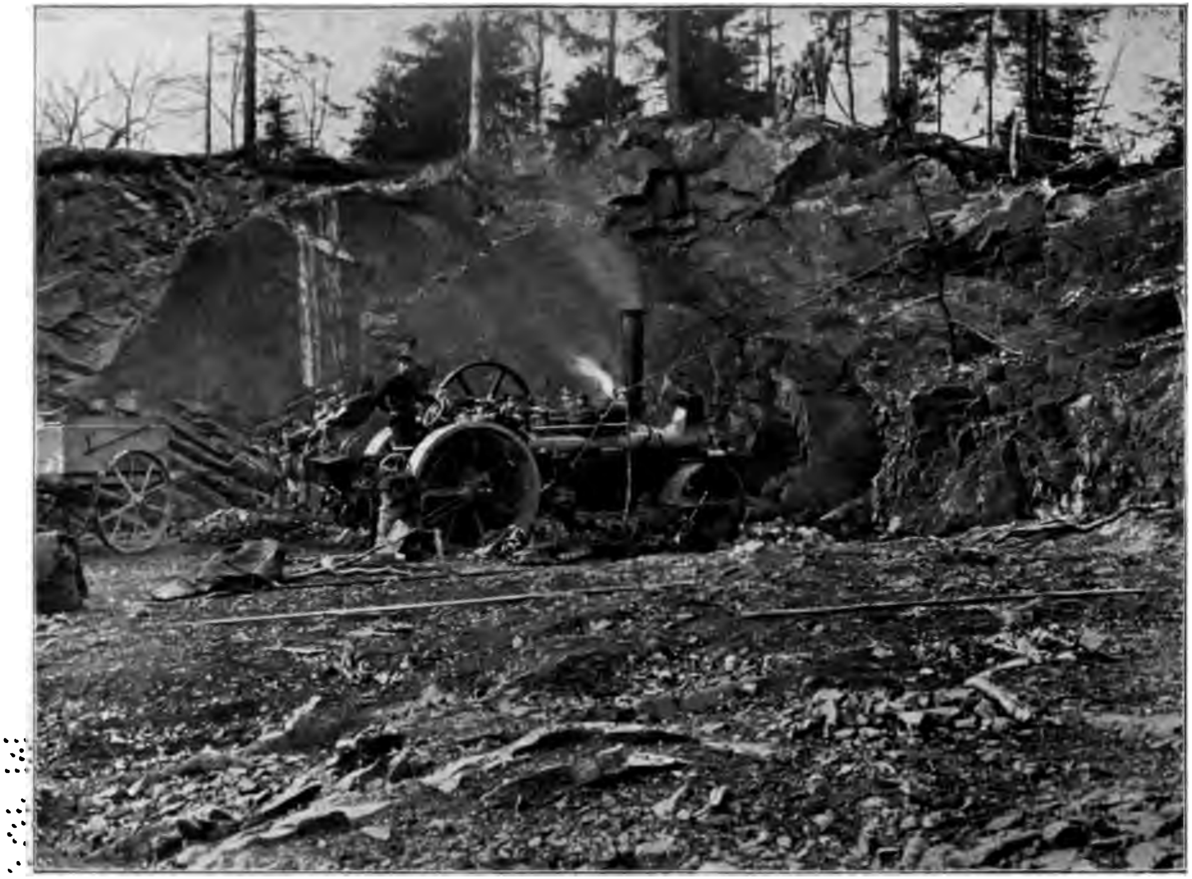

FIG. 92.—Road-stone quarry No. 2, showing drilling. [*To face p.* 186.

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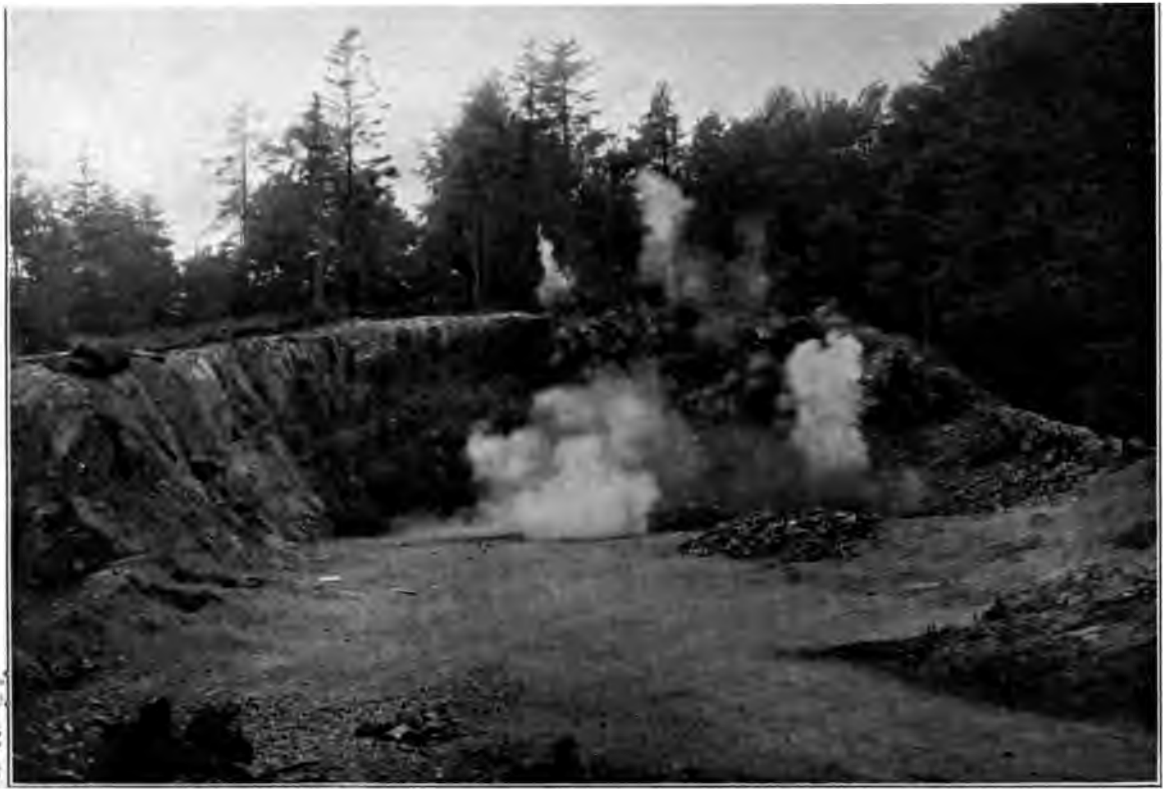

FIG. 93.—Road-stone quarry No. 2, showing face of quarry during blast. [*To face p.* 186.]

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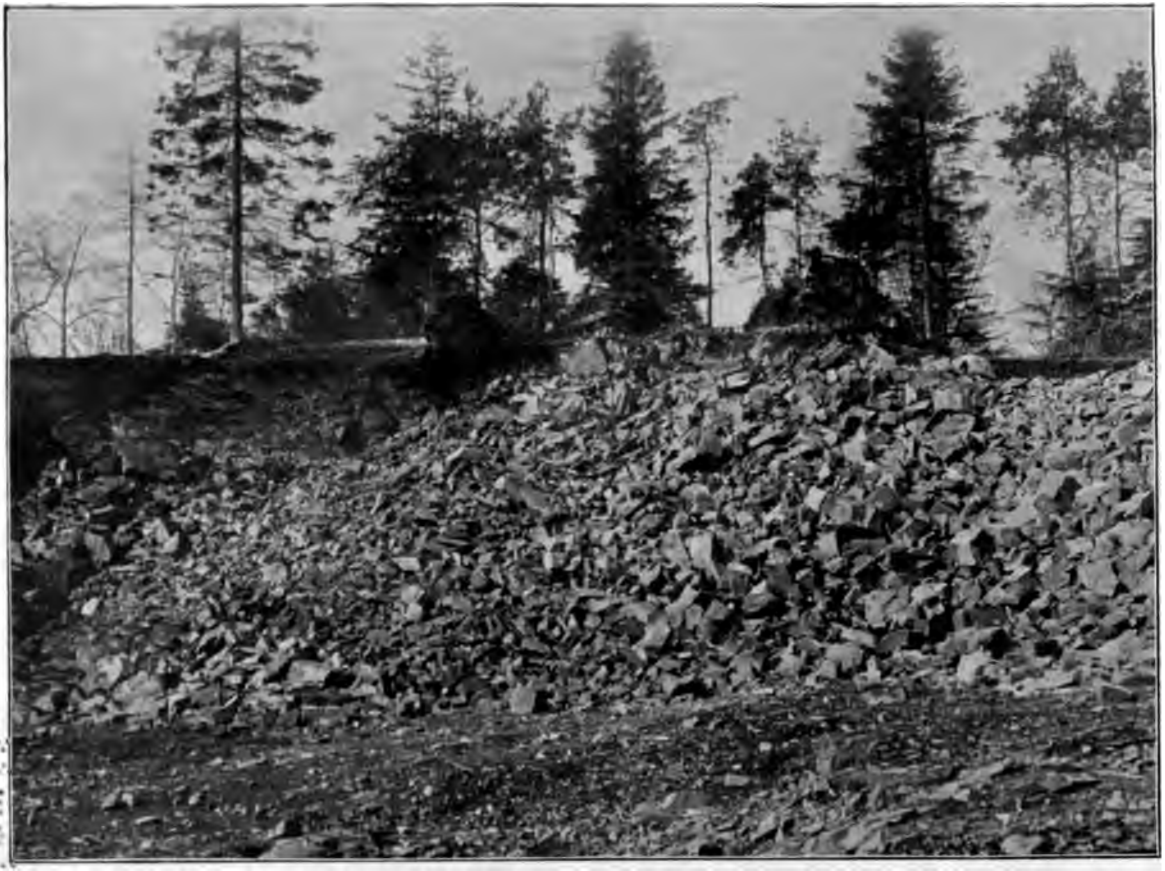

Fig. 94.—Road-stone quarry No. 2, showing result of blasting operations. [*To face p.* 186.

U of M

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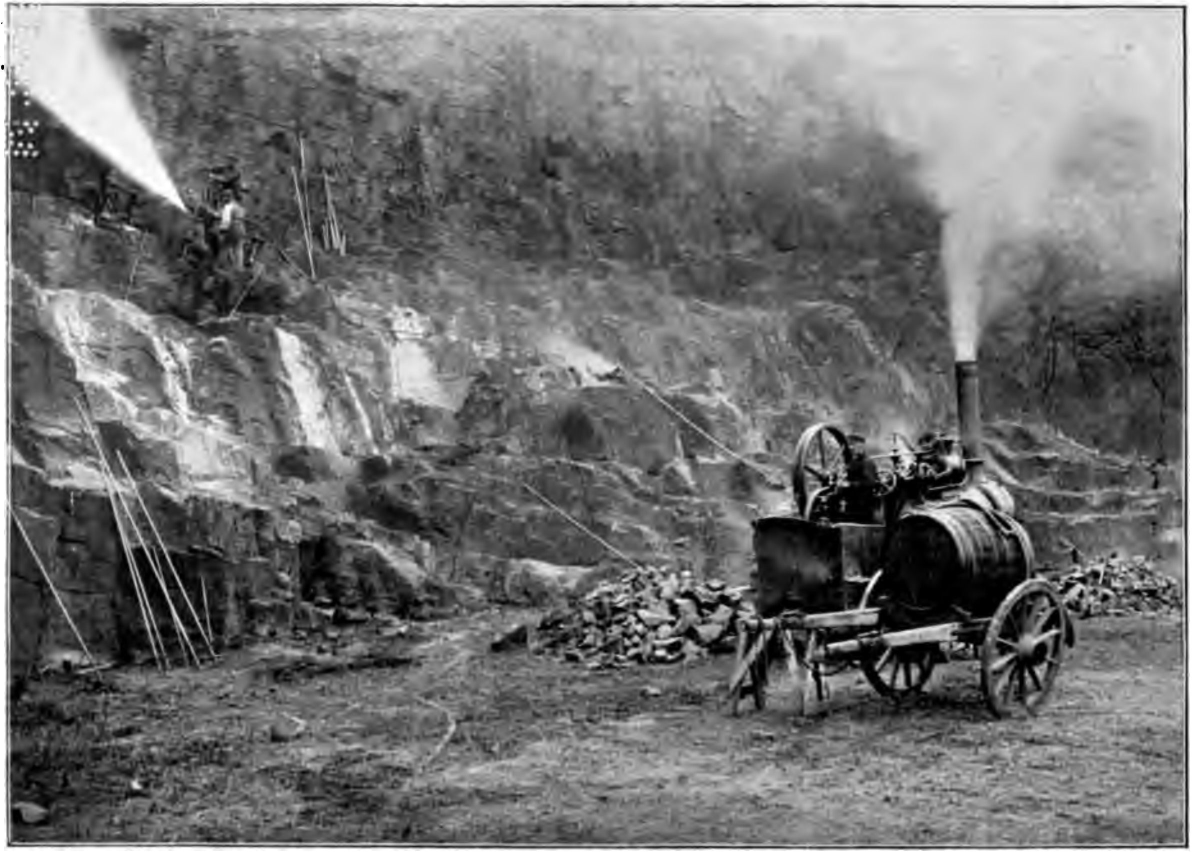

Fig. 95 —Road-stone quarry No. 3, showing drilling operations. [*To face p.* 187.

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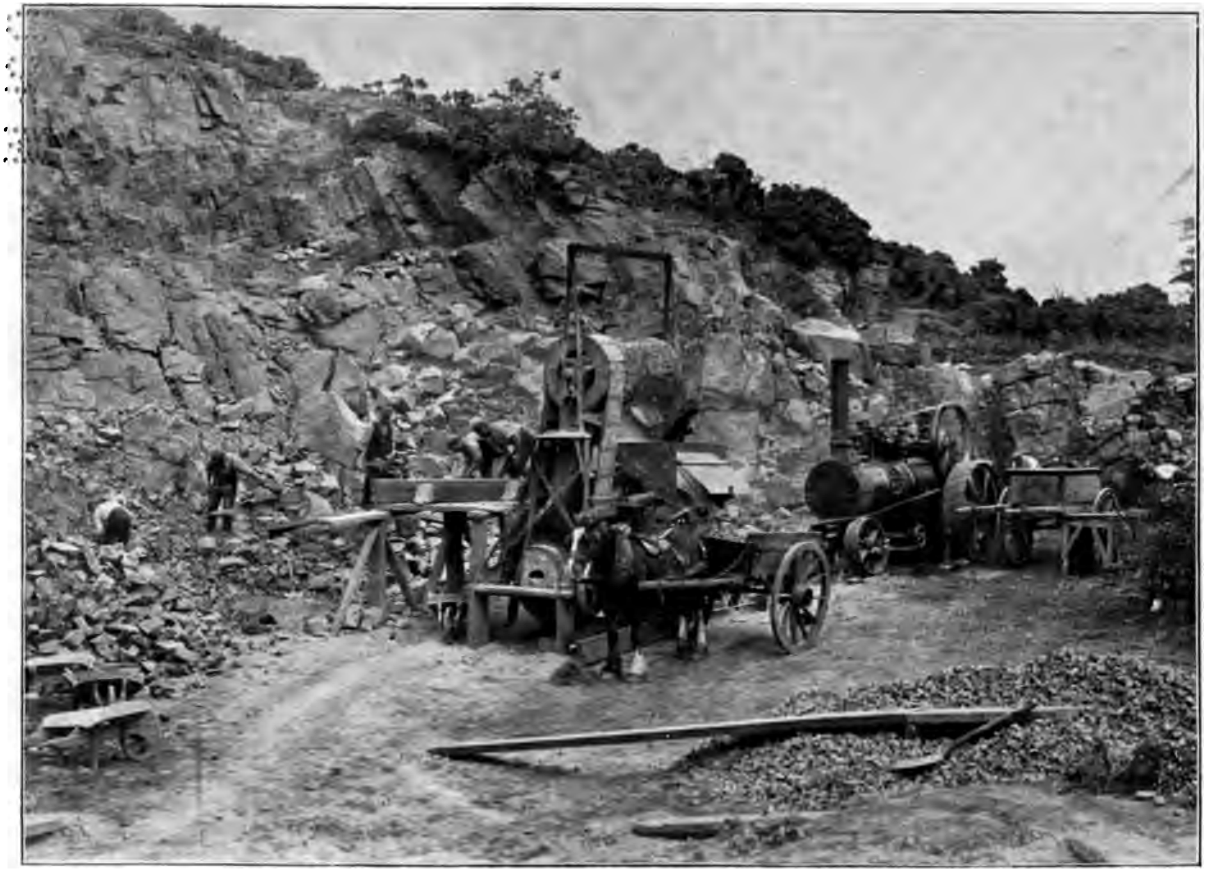

FIG. 96.—Road-stone quarry No. 3, showing result of blasting operations. [*To face p.* 187.

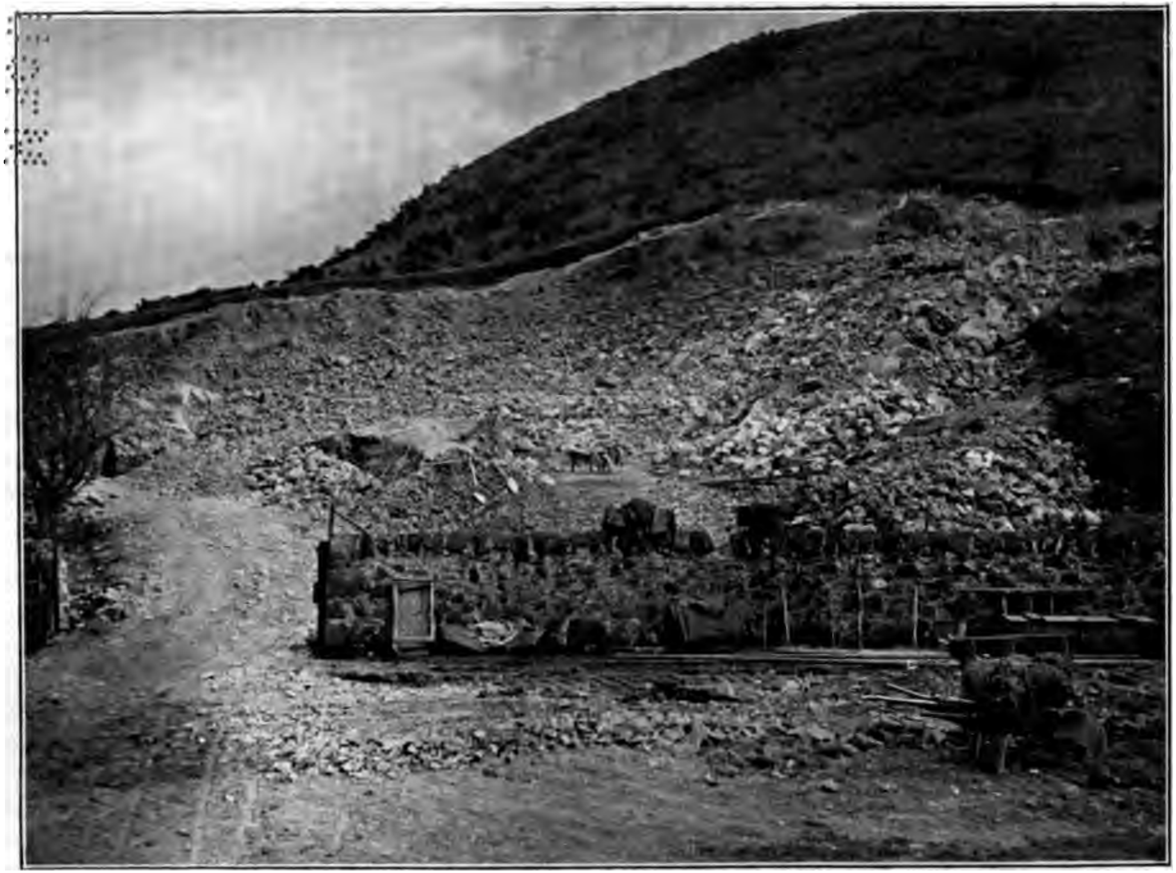

Fig. 97.—Road-stone quarry, showing result of blasting operations—5842 tons dislodged. [*To face p.* 187.

The cost of tirring in this case is exceedingly low, the rock being at the surface, with a few pockets of earth dispersed over the area operated on. The drilling turns out very well, considering the extremely hard nature of the rock. The cost of blasting is above the average; the character of the rock was such that in calculating the throw 10 tons of rock were considered sufficient for each pound of explosive used.

The sledging is a heavy item, the material when blasted being of a similar size to that of the previous quarry (road-stone quarry No. 2), but the tough and stubborn character of the rock necessitated additional men being employed to break it up in order to keep the stone-breaking machine constantly at work. It may be mentioned that this rock had defied the efforts of many contractors to put in a bore-hole, owing to the hard nature of the material. The jumpers could not be made to stand the work, 2 to 3 inches being all that it was possible to bore without re-sharpening.

The appearance of the quarry face, when the rock drill was working and previous to blasting, is shown in fig. 95, and the amount of rock dislodged after blasting is represented in fig. 96.

Fig 97 shows the result of blasting operations in a road-stone quarry when the quantity of rock dislodged amounted to 5342 tons after weighing.

196. The cost of quarrying by machinery and blasting, as detailed on p. 184, is a mean result of working in twelve different quarries, including those just described, and may therefore be taken as an average in estimating the cost of quarrying in connection with the production of macadam.

All the quarries under the author's jurisdiction are worked during the summer months only, and in order to arrive at the cost when drilling and blasting operations have to be carried on during the winter season also, an allowance must be made for the short day inseparable from this time of the year, and for other circumstances. The cost of labour, which of necessity varies in different parts of the country, will also affect the expenditure.

197. Cost of Quarrying by Manual Labour.—The cost of quarrying by manual labour, that is, by hand-boring, blasting with powder and fuse, including mashing or sledging, varies considerably, and may range from 10d. to 1s. 6d. per ton. For a small quantity of material which is to be removed from the quarry in an intermittent manner, the cost of quarrying one ton of rock reduced to a size suitable for the hand-breakers may be taken at 1s. 1d. This figure, in order to make a comparison with the method described in the foregoing paragraphs, is apportioned to the several items which make up the cost of quarrying one ton of rock. The following subdivision may be taken as an average, although some of the items vary widely in different quarries. The price for such work is usually quoted and paid for at so much per cubic yard; the cost of quarrying one ton of rock, therefore, has been deduced from it.

TABLE XXIII.

Cost of quarrying one ton of rock by hand-boring and single-shot blasting with powder and fuse, in the same quarries where the rock drill has been at work.

	Pence per ton.
Tirring or stripping (same as in Table XIX.), ...	0·68
Boring 1¼-inch holes, ...	4·19
Blasting—powder, fuse and caps, ...	0·82
Tamping and firing—time only, ...	0·31
Sledging or mashing, ...	7·00
Cost per ton quarried, ...	13·00

The cost of tirring is of course the same as in the case mentioned at p. 184, and the cost of the explosive and fuse is similar to that in the case of using dynamite in machine-drilled holes and firing electrically. The cost of boring by hand, however, is about 2¼ times greater than that of machine drilling, while the mashing or sledging is 2½ times as much as when the material is blasted with a high-grade explosive having a rapid and violent action, and the shot-holes are fired simultaneously by electricity.

When, however, the material is quarried by hand for a stone-breaking machine, the amount of rock necessary to keep the machine constantly at work is such that the limited length of face in most road-stone quarries precludes the employment of a sufficient number of men to keep up the necessary daily supply of material. Even if this were possible, the risk of damaging the breaking machine and engine while blasting, and the delays occasioned thereby, would curtail the output of macadam from it considerably. Another point which militates against this arrangement, assuming it was possible of attainment, is the increased distance the material would have to be wheeled, which would necessarily increase the total cost. When the rock which is to be broken by a machine is quarried by hand, it is necessary to start the quarrying operations months before the time when it is intended to commence breaking. The quarried rock must be stored in a cairn as high as possible, so that the labour of transporting the stones to the breaking machine may be reduced to a minimum. This at least will cost 2d. per ton, which, added to the expense of quarrying, makes an inclusive price of 1s. 3d. per ton of rock stacked ready for breaking operations.

198. Comparison of Cost by the two methods of Quarrying.—From these figures it is evident that a considerable saving is effected by the use of machine rock drills and blasting with high-grade explosives and electricity. The cost of quarrying by hand, as detailed in the foregoing paragraphs, and on the same class of rock as the rock drill has been at work on, shows in the first instance that there is a saving of nearly 49 per cent., and when the hand-quarried material is stored, of over 59 per cent.

It is obvious that the economical results obtained in quarrying rock by the aid of machinery are undoubtedly great, while the practical advantages are none the less striking. For instance, by the employment of a rock drill in boring the necessary holes, a quantity of from 1000 to 1400 tons can be quarried in one week, including blasting; this practically places the material in a state for breaking operations. This would mean, in order to produce by hand a like quantity of quarried material, the employment of twenty-four men each day for a similar period, or a boring squad of three men would be engaged forty days in performing a like amount of work.

199. Cost of Machine-drilling Plant.—The cost of a rock drill, including tripod, weights, steam-pipes, hose, blasting machine and cables, all of which have been described in the foregoing sections, amounts to £100.

200. The Storing of Explosives.—"The Explosives Act," 1875, regulates the manner of storing explosives, and the quantity which may be stored under certain conditions. It has already been pointed out how a great saving in cost is effected by obtaining any class of explosive in large quantities, and storing them. For instance, 2000 lbs. of explosive, more particularly the nitro-compounds, when delivered in bulk will cost about 35 per cent. less than the same amount delivered in small quantities at a time.

The difference in cost on the quantity mentioned will be £50, and the saving effected may be taken at £25 per 1000 lbs. of dynamite or other nitro-glycerine compounds.

The quantity of explosives which may be kept in a store varies according to the distance the building is from what are known as 'protected works'; licenses are granted under four divisions, viz., A, B, C, and D, and are defined according to Table XXIV.

TABLE XXIV.

	A.	B.	C.	D.
'Protected Works.'	300 lbs.	1000 lbs.	2000 lbs.	4000 lbs.
From a dwelling-house, shop, room, mineral or private railway, tramway, workshop, places where explosives are kept, furnace kiln or fire, yards	50	100	150	200
If the licensee occupies these 'protected works,' or the premises on which they are situated, or if the occupier gives his consent in writing, the distances are reduced to yards	25	50	75	100
Also from any public road, or path, promenade, canal, dock, river, or sea-wall, pier or reservoir, yards	25	50	75	100

	A.	B.	C.	D.
'Protected Works.'	800 lbs.	1000 lbs.	2000 lbs.	4000 lbs.
Also from any public railway, factory, church, college, school, court, market, theatre, hospital, or public building, yards	50	100	150	200
Also from any factory or magazine belonging to Government, yards	440	880	1320	1760
And from any palace or house of residence of Her Majesty, her heirs or successors, miles	2	2	2	2

Stores may be licensed to contain 'gunpowder' or 'mixed explosives,' and for the work in connection with the production of material for road purposes it is advisable to obtain a license for mixed explosives. The quantity of explosives under the divisions A, B, C, and D refers to gunpowder, and when the nitro-compounds are stored, ½ lb. is allowed in lieu of each pound of powder. Thus, in division D, 4000 lbs. of powder may be legally stored, or 2000 lbs. of dynamite or the other explosives of the nitro-glycerine class. If it be found necessary to store both these explosives, then a proportion of either may be kept; for instance, 2000 lbs. of powder and 1000 lbs. of any other explosive.

It is not permissible to store the means of ignition in the same place as the explosives, unless these are separated by a partition of such strength and character, or by such space, as will effectually prevent fire or explosion.

It is better, therefore, to store the detonators in a separate place or annexe situated near to the explosive store.

201. Description of Explosives Store.—The building must be substantially constructed of brick, stone, or concrete, or excavated in solid rock or earth, and not liable to ignition.

The plans of a suitable store for explosives of a 'mixed' description are illustrated in figs. 98, 99, 100, and 101. As the drawings are shown in detail, it is unnecessary to give a full description of them. A few points of importance, however, will be mentioned, attention to which may save trouble and expense in the upholding of the building, in meeting any reasonable demands of H.M. Inspectors of Explosives, and in interpreting the details of construction contained in the Act.

The store should be placed, preferably, in a dry situation; the foundation ought to be built on a firm and solid bottom, composed of concrete, if necessary.

The cheapest and at the same time a very efficient material for building a store is hard-burnt brick, and the thickness need not exceed 9 inches unless under exceptional circumstances. The roof should be in the form of an arch, but, in some instances, it is made of timber, covered with galvanized corrugated iron 22 B.W.G., screwed to the purlins, and bedded in cement at the gables and wall plates, as shown in fig. 102. Ventilators of a zigzag form should be constructed in the walls below the level of the flooring, immediately above it, and also at the roof of the store, a free circulation of air being desirable to keep the explosives in good order, while at the same time it aids in preserving the woodwork in the interior of the building. These should be protected on the outside with cast-iron perforated plates or bricks, and on the inside with wire cloth. The exterior of the building should be covered with a coating of cement, to ensure its being perfectly waterproof.

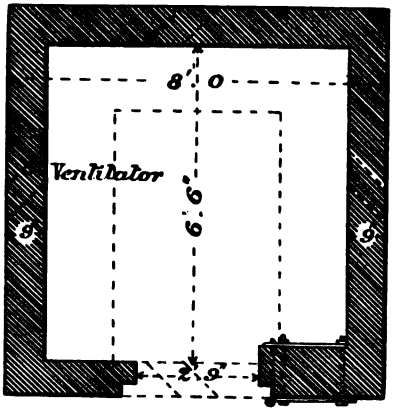

FIG. 98.—Plan of explosive store.

Double doors of wood are sometimes provided, but a door-frame of wood lined on the inside is quite sufficient. To properly protect it from being tampered with, a sheet of iron $\frac{3}{16}$ of an inch thick should be spiked on

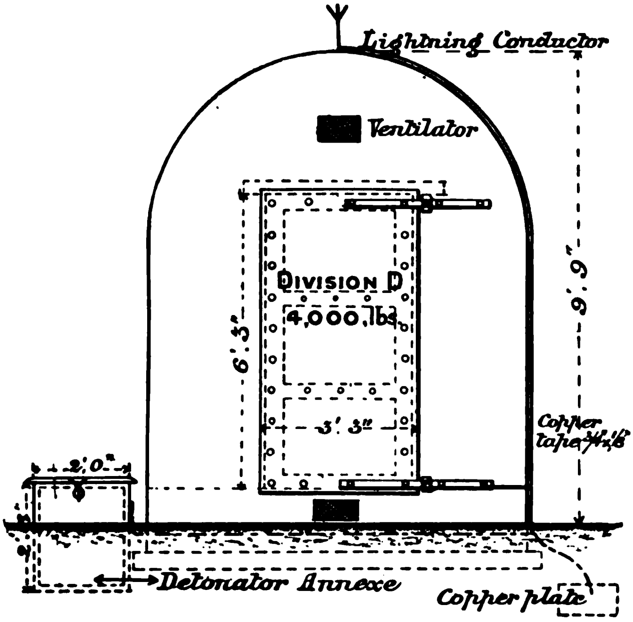

FIG. 99.—Elevation of explosive store.

to the outside of frame, so as to slightly overlap both it and the recess, which is formed of angle irons, as shown in the drawings. The side at which the door is hung should have the brickwork 14 inches thick, while the arms forming the hinges should be fixed by through bolts and iron plates inside. The flooring must be of timber, the interior of the store must be lined with wood, and these, along with the shelving, must be fastened with copper, brass, or zinc nails, or with iron nails countersunk and puttied.

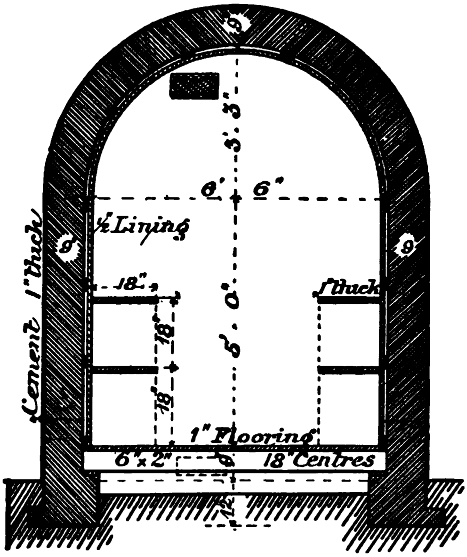

FIG. 100.—Section of explosive store.

The woodwork should be finished by applying two or more coats of varnish. The lock should be of brass, and all iron, where exposed internally, properly protected. It is essential to provide a lightning-conductor, which may be made of ¾-inch round iron, or of copper tape ¾ inch by ⅛ inch, properly fixed to the outside wall, as shown, and terminating in the earth, preferably

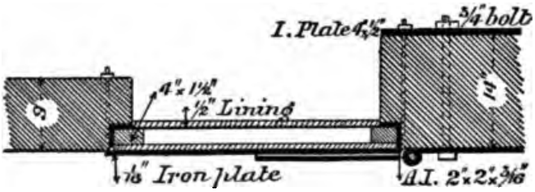

FIG. 101.—Details of door.

damp soil, 2 or 3 yards distant from the store and 3 feet deep, with a copper plate 20 inches by 12 inches and ⅛ of an inch thick. All exterior ironwork should be put in metallic connection with the conductor, the upper end of which should be 18 inches above the highest part of the building, and terminate with three branches pointed; these should be gilded or finished with platinum caps to resist oxidation. It is necessary to keep the floor and shelving of the store free from grit, for which purpose they should be swept periodically, and occasionally washed.

202. Annexe for storing Detonators.—The detonator 'annexe' is best formed by a box made of iron ¼-inch thick, 2 feet by 2 feet, and 2 feet 6 inches deep, sunk three-fourth part into the ground. The lid should project 1½ inch over the box, and be slightly bent downwards at the outer edges to prevent wet gaining access. The lid should be provided with strong hinges and brass padlock. The interior of the box should be lined with wood, and have a suitable inner lid or cover. This annexe may be placed as shown in fig. 99, just clear of the wall of the explosives store. An additional safeguard in the form of a high and close fence may be erected a few feet distant from the store, completely surrounding it, and having a suitable access in front. It is necessary to provide a pair of boots without steel or iron about them, or a pair of goloshes, to be used by those entering the store. These should be of a size large enough to wear over the ordinary boots or shoes. As a convenient road to the store is a necessity, the site selected for the store will mainly depend on the facilities for making and properly maintaining such a road.

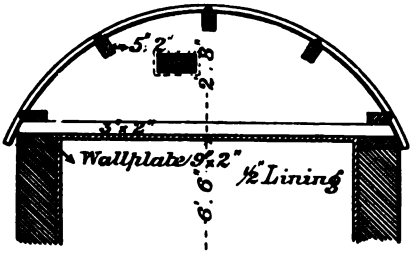

FIG. 102.—Timber roof for store with galvanized covering.

203. Cost of Erection.—The cost (exclusive of the road access) of erecting an explosives store of the dimensions given in the drawings will vary according to the place in which it is erected; but the expenditure may be taken at from £22 to £28, if the brick arch is adopted, and about £18 to £22 when the roof is formed of timber and galvanized corrugated iron, as shown in fig. 102. The construction of the explosives stores shown in the preceding drawings is of a substantial character; erections of a less permanent nature, however, may be built of a combined wood and galvanized construction. The cost of the latter method will therefore be considerably less, probably one-half.

204. An excerpt from the Explosives Act should be affixed on the outside fence; and the rules and regulations should also be hung up inside the store, while the class of the Division should be painted on the outside of the door in large letters in the following manner:—

DIVISION D. 4000 lbs.

CHAPTER VI.

STONE BREAKING AND HAULAGE.

Stone Breaking.

205. The material described in the preceding chapter requires a further reduction in size before it can be applied to the highways or stored for subsequent use.

General Conditions relative to Hand-broken Macadam.—If the macadam is for coating the top of a newly constructed road, or for strengthening an existing one the crust of which has, through neglect or other causes, become reduced to such an extent that the material forming the bottoming is exposed, then it is necessary to apply metalling the stones of which will pass through a 2½-inch ring, or weigh about 6 ounces. For general surface repairs, however, metalling of a somewhat less size may be advantageously made use of. The smaller the size the smoother will the surface of the road be; but the size of the metal for any particular section of a road must be determined to a certain extent by the amount of traffic which it will have to bear, and the nature of the rock from which the macadam is produced.

On roads over which the traffic is heavy, the tougher kinds of rock, such as basalt and dolerite, should be of a size which will pass through a 2¼-inch ring; while with the same class of material, but applied on a road with only moderate traffic, the size may be advantageously reduced to pass through a ring 2 inches in diameter. The weights of these different sizes are approximately 4 ounces and 3 ounces respectively. Rock of a hard and brittle nature will give better wearing results when broken to a size somewhat larger, while flints and the harder limestones will be most suitable for surface repairs if broken to a size the weight of which varies from 6 to 8 ounces.

To ensure equal wearing, and consequently a smooth surface, the metal should be broken to a uniform size and to a form as nearly cuboidal as possible. Irregularly-sized metal cannot resist the wear and crushing effect caused by the wheels of vehicles, engines and wagons; consequently a bumpy surface is formed, or, in other words, it becomes 'cupped.' Under these circumstances the wear is increased, and the surface of the road becomes irregular, and horses and vehicles suffer in proportion.

206. These are briefly the main points necessary to be considered in determining the best conditions under which hand-broken metal is applicable to road repairs, especially when the material is intended to be consolidated by wheel traffic. The breaking of metal specially to a small size for ordinary repairs, although of great advantage to the road under certain conditions, increases the cost of production, and in most cases a proportionately larger amount of small stuff is produced. This fine material is of little or no value on the road, and under certain conditions its presence is pernicious; to avoid this evil it is necessary to screen the material so as to separate it from the regular-sized stones. This additional manual labour increases the cost of production, which, at a low estimate, may be taken at 3d. to 4d. per cubic yard.

207. Quantity of Macadam broken by Hand per Day.—A good hand-breaker can produce from 3 to 4 cubic yards of ordinary macadam per day out of such material as flints, the harder limestones, field stones, and river gravel. Whinstone of a brittle nature, when the rock is reduced to a size similar to that mentioned in the preceding chapter on quarrying, may be broken by hand at the rate of 2 to 2½ cubic yards per day, while hornblendic-granite, basalt, and the tougher kinds of whinstone can be broken up at the rate of from three-quarters to one and one-half cubic yards in a similar time. The number of hours which a man works when breaking road metal depends upon circumstances. If engaged on piece work a hand-breaker may work for twelve hours on a stretch, producing more material than one who is less physically capable, or who is engaged to break at so much per day.

208. Cost of Hand-breaking.—It is thus a somewhat difficult matter to arrive at the actual cost of breaking road metal by hand, but an approximation sufficiently correct can be obtained by measuring a heap of metal which has occupied a hand-breaker a certain time to accomplish. This will give the amount broken each day of nine or ten hours; but, in addition to this, the wages which are paid in any particular locality will have to be considered as influencing the cost of production. Taking these circumstances into consideration, the experience of the author is that the cost of breaking by hand varies from 1s. 3d. to 2s. 6d. for each cubic yard of road metal. The supplying of macadam for repairing and maintaining roads under the old or patching system is in most cases regulated by annual contracts. The price in some instances is stated separately for quarrying, carting, and breaking; but generally these contracts are arranged for at an inclusive figure, the metalling being deposited alongside the roads at convenient points or in depôts.

The price per cubic yard of metal thus laid down will vary according to the conditions already mentioned, and, in addition, the cost of hauling or conveying it from the quarry to the roadside depôts. Where the distance is great, the cost of carting may increase the price to double the actual amount of producing the macadam itself.

209. In districts where suitable rock for road purposes does not exist to any great extent, the metalling may have to be brought from a distance either by traction-engines and wagons or by rail, which, besides the heavy charges for haulage, entails in many instances double handling of the material. In those districts where local stone of a suitable quality can be obtained within a reasonable distance of where it is to be applied, the cost of quarrying, breaking by hand, and carting to the roadside depôts, an average distance of two miles from the quarry, may be 3s. 10d. per cubic yard. This is an exceptionally low figure, and can only be executed under the best possible conditions of work, while for material which is difficult to quarry, and which takes 2s. 6d. to break by hand, the cost will be 5s. 7d. per cubic yard when laid down in depôts at a similar average distance. The latter price is one that is very usually met with in practice under ordinary conditions, and as the distance to which the material has to be conveyed increases, the cost of supplying macadam may rise to 7s. or 8s. per cubic yard, and even to 10s. in exceptional cases. In quarries worked under the authority of County Councils, it is, as a rule, only necessary to pay surface damages for the ground destroyed in obtaining the materials. This amount may be allowed for either in the cost of quarrying and breaking, or stand as a separate item, but generally the additional cost per cubic yard of material is very trifling in amount, especially when the face of the quarry is high, or the relative quantity of metal removed is large compared with the area of ground occupied. In sale quarries, however, the actual cost of the material is increased by an additional charge for lordship, or quarry rent, which varies considerably, but may be taken at from 4d. to 6d. per ton or per cubic yard of rock.

The race of hand-breakers is, however, fast disappearing, especially in rural districts, and the high price now demanded for this class of labour requires that other means be adopted for producing macadam. The obvious necessity in these days, owing to the altered condition of trade and traffic, of attaining a higher standard of perfection in road maintenance, and of applying larger quantities of material to strengthen and improve the condition of the highways, is a further incentive to the employment of stone-breaking machinery.

210. Requirements which a Stone-breaking Machine should possess.—Objection has been taken against stone-breaking machines in some localities, on the ground that they fracture or crush the stones, make the edges rounded, and produce metal which is not uniform in size.

No doubt the earlier types of stone-breaking machines were open to these objections, and they may even still exist to a considerable extent in some of those employed at the present time; but they do not apply to the modern 'stone-breaker' with its almost perfect mechanical movements.

In a good machine the rock should be sledged by the upper set of jaws, and the teeth be spaced at a comparatively wide pitch and so arranged that the ridges will work in the furrows immediately opposite. The stones, after passing through the upper jaws, should be cubed by the lower ones, and means should be provided to admit of the material changing position and readjusting itself, so as to prevent spalling or the production of long thin pieces.

Provision should be made to admit of an increase or decrease of the movement of the reciprocating jaw, which acts on the rock between it and the fixed jaw.

The mechanical construction should be simple, strong, and effective, while the working parts should be arranged so as to reduce the strains on the driving shaft to a minimum. The strains should always be in one direction, while the toggles should finish in a straight line at the completion of the forward stroke. The machine and accessories ought to be capable of effectually screening the material, so that the macadam resulting from the breaking operations can be distributed, stored, or loaded automatically. In many cases where machine-broken metal is used, and condemned as inferior to that broken by hand, without the material being properly sized, it is invariably found to be caused by a want of proper gauging of the macadam by screening. To apply the stones direct to the roads as it leaves the jaws of the machine, is simply to make use of it in an unfinished state of manufacture. The appearance of a piece of rock after a hand-breaker has broken the larger-sized stones with the light mashing or sledging hammer, and before finishing his work with the small hammer, is similar in appearance to the larger-sized pieces of stone which have been only partially broken in passing through the jaws of the machine. It is the proper screening of the metalling which makes machine-broken metal a success, the larger pieces again passing through it automatically, to be broken to a proper size.

With many types of stone-breaking machines, the extent of the motion of the reciprocating jaw is constant, so that under certain conditions, as when breaking hard rock, of an acid nature, numerous flaky pieces are produced, which, besides making a bad sample of road metal, quickly deteriorate in the road under traffic.

If a stone-breaking machine is so constructed that the pressure or blow can be regulated by either a long or a short movement, the production of flaky road metal will be reduced to a minimum. By giving the swinging jaw a short travel, by means of a rearrangement of the toggles, hard brittle rock can be properly treated; while for tough or stubborn rock the movement should be made longer.

211. The macadam produced by a good stone-breaking machine may not present such a cuboidal appearance as that produced by hand-breaking, but for general purposes it is little inferior in quality; the cost of production, always a determining condition in such matters, is greatly in favour of machine-broken macadam, while the possibility of producing large quantities of macadam in a short space of time is an additional advantage. In quarries where road metal is produced in large quantities, the breaking operations are carried on more or less during the whole year, for which purpose it is necessary to fix the plant or the 'stone-breaking mill' at a convenient and safe distance from where the quarrying and blasting operations are carried on.

212. The breaking machinery should, if possible, be situated at a lower level than the quarry floor, in order to admit of the haulage of the material by bogies or cars being effected by gravitation. For a similar reason the position of the breaking plant, in regard to the disposal of the broken material, should be such as to admit of the screening being carried out immediately after the material passes through the jaws of the breaker. It can then be conveyed in shoots to the points where it is to be delivered direct into wagons or carts, or into storage bins for future use. It often happens, however, that the physical conditions of the ground will not admit of this arrangement being carried out, a circumstance which necessarily involves a system of working not so favourable as when the material can be disposed of by means of gravitation alone. When the height of the quarry floor above the level of the sidings or storage bins is such that the breaking, screening, and delivery arrangements can be properly accomplished, the haulage of the rough stones from the quarry face to the stone-breaking plant may be conveniently performed by steam haulage. When the quarry and the point of delivery are on the same level, it becomes necessary to make a suitable erection sufficiently high for the accommodation of the breaking, screening, and delivery plant: the haulage of the material to the feeding platform must in such cases be accomplished by means of a rope working on a drum, an aërial ropeway, or some other suitable arrangement.

213. A proper system of distributing the different sizes of macadam, when it is to be stored, is, of course, best carried out by gravitation; in most instances, however, it has generally to be performed by the aid of conveyors. It seldom happens that the plant can be so placed in relation to the quarry as to be so favourably situated that the haulage, tipping or dumping, and the screening and delivery of the material can be accomplished entirely by means of gravitation.

It will be evident from the preceding observations how essential it is, when laying down a stone-breaking plant, to arrange the machinery and appliances so that the cost of handling the material and operating the plant may be reduced to a minimum. These particular requirements apply more especially to quarries where a fixed plant is indispensable, by reason of the demand for macadam, and which may necessitate continuous working of the stone-breaking plant during the whole or greater part of the year.

The immense quantities of road metal which are produced in many of the larger sale quarries to supply the requirements of counties and towns which do not possess suitable rock for road purposes within their own jurisdiction, necessitate the employment of a large number of stone-breaking machines at these centres.

The arrangement generally adopted in these circumstances is to make use of a 'set' of stone-breakers; the leading or 'reducing machine' having a large breaking capacity, sledges the rock to a certain size, which is then directed by shoots into two or more other machines, which break or cube the material to a size suitable for macadamizing purposes.

214. 'Sets' of Breaking Machines.—Double, and in some cases treble, sets of stone-breaking machines are made use of in quarries where the rock is of a recognized quality, and the demand for metalling is considerable. Under these conditions the machines are fixed permanently, and, if possible, on solid foundations, as when so placed the actual amount of work performed is considerably increased compared with that obtained from machines fixed on a timber erection, which, although it may be well constructed, admits of vibration taking place when the machinery is in motion, whereby the output of the machine is reduced.

215. The original stone-breaking machine was invented by E. W. Blake, of Newhaven, Connecticut, and was introduced into England in 1860, by the late Mr. Marsden of Leeds, who effected many alterations in the construction of certain parts in his endeavour to adapt it to the requirements of this country.

Since that time many alterations and improvements in the mode of construction have been introduced by engineers, so as to reduce the strain on the working parts, and the motive power necessary to drive the machine, while the form of the jaws has been modified so as to produce cuboidal macadam.

Mechanical Details.—Previous to giving a detailed description of the different parts of a stone-breaking machine, it will be convenient to mention some special points which, in addition to those already stated, a machine of this description should possess.

It must be capable of withstanding the great wear and tear incidental to this class of machinery and of producing a uniform size of macadam.

The construction must be on such a principle as to avoid excessive strains on the driving shaft, and yet be simple and strong.

It must have as few working parts as possible, and the arrangement of the reciprocating jaw should be such as to admit of a sharp and powerful blow being given.

The strains brought about on the working parts when breaking stones should be maintained in one direction, and the wearing parts should be easily renewable. The breaking of the rock should be accomplished either by two machines working in conjunction, or by one with specially constructed jaws. In the former case the material is sledged or reduced sufficiently small for the second machine, which cubes it to the desired size for metalling; in the latter case, the jaws are so arranged that the process of reducing the rock is accomplished by the upper jaws, while the metal is cubed by the lower ones.

The screening of the material and the conveying of the 'rejectors' or large pieces of stone back through the breaker jaws again should be performed automatically. By this arrangement the jaws of the breaking machine can be fixed sufficiently open so as to admit of a considerable proportion of large pieces being passed a second time through the machine, thus yielding a better sample of macadam and producing a minimum quantity of screenings.

216. Description of Blake's Original Stone-breaker.—The original Blake stone-breaker is shown in fig. 103, which represents an elevation in longitudinal section of the machine. It consists of a cast-iron frame X, with a vibrating or swinging jaw A, which approaches to and recedes from the fixed jaw B, by means of the toggles C, attached to the pitman D. It is actuated by the lever E, working on a fulcrum F, and attached to the connecting rod G, working on a crank shaft H. On this shaft are placed the fly-wheels I, and pulley J, by which the power is transmitted to the machine, the size to which the macadam is intended to be broken being regulated by the wedge K, which can be raised or lowered by the screw L working on the toggle block M; the draw back motion being effected by means of the rod N and spring O. This machine was essentially a crusher, the teeth of the jaws being vertical and interlocking each other, so that the ridges of the one jaw were set opposite and worked against the furrows of the other. No attempt was made, by reason of the construction of the jaws, to cube the material; it was a powerful machine, however, and capable of any amount of work.

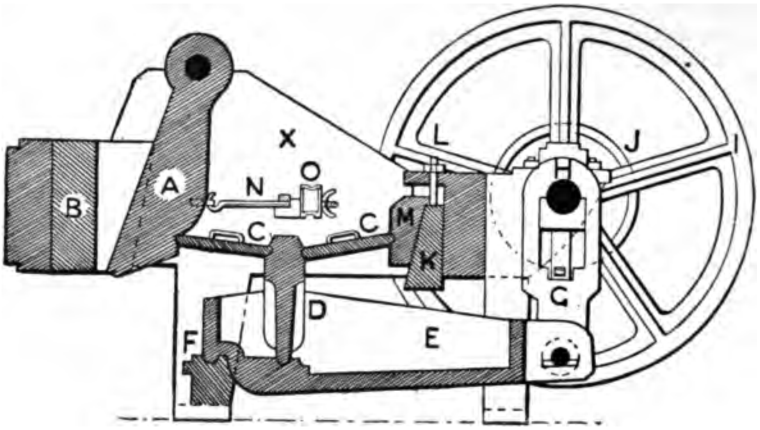

Fig. 103.—Section of original 'Blake' stone-breaking machine.

217. Archer's Breaker.—An attempt to cube the material was made by Archer, and after various endeavours he brought out a machine in 1867. It consisted of a cast-iron frame, with a slotted crank shaft—running in bearings at the end of the machine,—which operated a large lever working on a fulcrum pin. The back end of this lever was connected to the crank by a variable link, which controlled the position of the crushing faces in relation to the rotating toothed roller, fixed on a shaft and actuated by spur gearing The front end of the lever was curved so as to partly encircle the rotating roller, and was provided with corrugated faces in the upper and lower jaws, while the teeth of the roller were placed at right angles to the corrugations in the lower jaws. This machine produced a fair sample of metal, but the wear and tear were so excessive and the number of breakages were so numerous, that it was not a practical success, while the amount of work done was considerably less than that of the Blake machine.

This stone-breaker was further improved by Archer, in that a small Blake jaw was utilized for breaking the stones, in conjunction with a lever having a curved face working against a revolving toothed-roller. At the rear end of the cast-iron lever a slotted crank shaft was fixed to transmit the motion to the machine, and on which the fly-wheels with driving pulley were secured. The crank shaft was connected by a link capable of being made longer or shorter according to the size of metal required, and fixed to the lever by a spindle. The lever rocked on a shaft, which also carried a pinion wheel; while rocking it actuated the breaking jaw by means of blocks connected by a bolt running through them from the jaw stock, and attached to the lever by an india-rubber spring and nuts. This arrangement also gave the necessary pressure to the jaws working against the revolving roller. The rotating motion of the horizontal toothed roller was effected by spur and pinion wheels driven by a belt running on a pulley fixed on the fly-wheel, and another pulley mounted on the shaft which carried the toothed roller. It is obvious that this form of construction did not follow the best and simplest mechanical movements, and although it was a decided improvement on the former machine, still the great wear of the working parts and the strains to which it was subjected when working, told seriously against it as a practical and economical macadam-breaking machine.

Many different forms of construction have been adopted from time to time by quarry owners and others to attain a proper working machine which would produce a satisfactory sample of macadam. The general method followed of accomplishing this was either that of using two machines, one for sledging the rock, and the other for reducing it to road metal, or of using one machine only and directing the broken material by a shoot to a system of rolls, which acted upon the long or flaky pieces of stone, reducing these to an approximately uniform size.

218. 'Excelsior' Breaker.—In the year 1872 a stone-breaking machine, known as the 'Excelsior,' was brought from Australia to this country. The inventor, Mr. Hope, introduced special features into his machine in order to obtain a superior cubing arrangement.

This stone-breaker is shown in sectional elevation in fig. 104. It will be observed that the lower part of the swinging jaw A is curved backwards, the teeth forming the face of the jaw being continuous from top to bottom, and made to a pitch of 3 inches. The fixed jaw B had the teeth upon its upper portion placed so as to work in the furrows of the opposite jaw, while towards the lower end the teeth were altered so as to work against and opposite the ridge of the teeth in the swinging jaw. The object of this was to break the long or flaky pieces before they left the machine. The method of operating the mechanism was carried out by means of the usual fly-wheels I and pulley J, fixed to a crank shaft H. A connecting rod G attached to the crank shaft and fixed to the upper end of the rocking lever D, working on a spindle, communicated the motion to the toggle C, causing the swinging jaw to reciprocate. The drawback movement was provided for by means of a rod N and india-rubber spring O, the rocking lever being held in position by a similar arrangement. This stone-breaker possessed many valuable mechanical features, but, owing to the arrangement of the jaws, did not provide for the stones readjusting themselves while passing through, consequently the cubing of the material was not satisfactory.

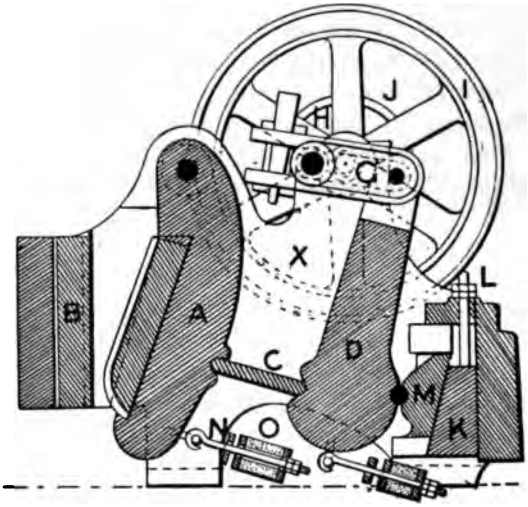

FIG. 104.—Section of Hope's 'Excelsior' breaker.

This breaking machine was used in a few of the counties in Scotland for many years, and performed good work where the rock was of a tough and stubborn nature; but these machines have now been superseded by stone-breakers of more modern construction.

219.—The late Mr Marsden made a further attempt to improve the cubing of the material with the Blake machine by a rearrangement in both the swinging and fixed jaws, into which three bends were introduced with alternate ridge and furrow teeth working opposite; this alteration, however, proved unsuccessful both in regard to the output of the machine and the amount of waste caused by the stones being crushed.

Marsden's Stone-breaker.—The design of the face of the jaws was altered to different forms from time to time as experience was acquired; the present arrangement of the teeth in the swinging and fixed jaws of the Marsden machine is shown in fig. 105. It will be observed that the jaws are composed of four parts, and can be renewed as they become worn, the break between them admitting of the stones changing their position, ensuring a better sample of macadam being produced than with jaws having teeth continuous from top to bottom. The mechanism and working of this stone-breaking machine may be thus described. The main frame X, fig. 105, is of cast iron. The swinging jaw A is suspended from a shaft and breaks the stones by vibrating against the fixed jaw B. The motion of the swinging jaw is obtained through the toggles C, working in grooves in the swinging jaw and block M, while similar grooves are made in the connecting rod G, which is made to rise and fall by means of an eccentric fixed on the shaft H, which carries the fly-wheels I and driving pulley J.

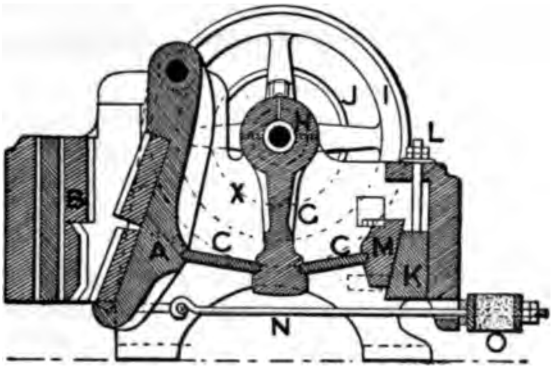

Fig. 105.—Marsden's stone-breaking machine.

When the connecting rod is at its highest point on the eccentric the toggle plates are nearly in a straight line, thus producing a direct strain through the toggle plates from the swinging jaw A to the block M. In raising the connecting rod from its lowest point, however, or when the jaws are opened to their extreme width, a considerable torsional strain is brought upon the connecting rod, and also on the shaft carrying the eccentric and fly-wheels. For this reason a crucible cast-steel connecting rod has been substituted to minimise the breakages inseparable from this form of construction. To produce fine or coarse macadam, the swinging jaw can be opened or closed by means of the screw L and wedge K. The drawback movement is provided by the rod N, attached to the lower part of the swinging jaw, and fixed to the back end of the machine by means of an india-rubber spring O.

220. **Blake-Marsden Stone-breaker.**—Another type of stone-breaking machine, made by Marsden of Leeds, is shown in sectional elevation in fig. 106. It is known as the improved Blake, or lever hand hammer motion stone-breaker. The letters indicating the different parts of the machine are arranged as in fig. 105. The principle followed is somewhat similar to that of the original Blake, but, as in all machines constructed on the lever principle, there are excessive strains due to working at high speeds, and to the rapid reciprocating action of the jaws and moving parts. The different types of stone-breaking machines made at the present time are too numerous to describe in detail, so that only a few besides the Marsden and Blake-Marsden machines will be mentioned.

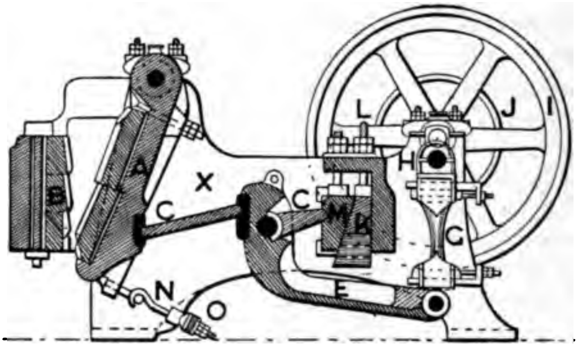

Fig. 106.—Blake-Marsden hand lever motion stone-breaking machine.

221. Mr. C. E. Hall introduced a breaking machine in 1867 having a multiple action; that is, the jaws are divided into two parts vertically, and driven separately by a double eccentric on a main shaft; in other words, one jaw recedes as the other advances. The action of the connecting rod on the eccentric shaft is, as already pointed out, an objectionable feature, owing to the excessive and continual strain which it has to withstand. 'Broadbent's' and also 'Mason's' stone-breakers are similarly constructed; that is, with toggles and a connecting rod working direct on a shaft by means of eccentrics. These machines require great power to set them in motion, and also to drive them, while the principle on which the eccentric works in this class of stone-breakers is such that a considerable amount of power is lost in lifting the mechanism against the work which is being performed. Notwithstanding the mechanical defects mentioned, a considerable number of Broad-

bent's machines are working in different parts of England, especially in the Clee Hill district.

222. The stone-breaking machine which has for many years back been extensively used, and proved most satisfactory in regard to breaking capacity, quality of the macadam produced, reduced wear and tear, economical working, and the small amount of motive power necessary to drive it compared with all the others mentioned, is that patented and made by Mr. W. H. Baxter of Leeds. This stone-breaking machine combines many valuable improvements suggested by practical experience; the portable type of machine with the automatic screening and loading appliances has supplied a great want, and at the same time made certain work attainable which with the machines formerly in use was impossible.

Baxter's Stone-breaker.—The stone-breaker (16 inches by 9 inches) known as "Baxter's Patent Combined Portable Stone-breaking, Automatic Screening, and Loading Machine," will be described, while the actual amount of work which it is capable of performing and the cost of producing macadam will be given in detail. Various sizes of this type of stone-breaker are constructed, the largest made being known as a 24 in. by 15 in. machine, this being the size of the opening between the jaws where the rock is fed into the machine; it has a guaranteed breaking capacity of 16 tons per hour; the smallest size, 6 in. by 4 in., breaks 30 cwts. of rock per hour. The size first mentioned, namely, a 16 in. by 9 in. stone-breaker, is the most suitable machine for general use in quarries worked under County Councils, for providing macadam for renewing and repairing the highways. The breaking capacity of this machine is from 60 to 80 tons per day, which amount of macadam, hauled direct to the roads under repair, will provide constant work for a 15-ton roller in consolidating the metalling. This arrangement obviates storing the material in the quarry, always an expensive operation, which will be referred to further on. A sectional elevation of Baxter's machine is shown in fig. 107. As in those already described, there is a cast-iron frame, X, having suitable flanges cast at the lower corners for fixing the wrought-iron axles, and to which the collars, swivel, and foot plate are secured, for the road wheels; while means are provided for steering at the front end.

A fly-wheel, I, is fixed to the outer end of the crank shaft H on either side of the frame, and to one of these wheels the driving pulley J is attached. The crank shaft in rotating conveys, by means of the connecting rod G, motion to the rocking lever D (the weight of which is sustained by a shaft D^1 at its lower end, on which it rocks), and actuates the toggles C C. These in turn provide for the 'knapping motion' of the swinging jaw A, which is held in position by a shaft A^1 at the upper end, and gives the necessary force to break the rock between it and the fixed jaw B. The ends of the rocking lever shaft are fitted into slide blocks placed in a rectangular recess on each side of the frame, and are held rigidly in a vertical position by means of an iron strap and bolts. This arrangement admits of the swinging jaw being opened or closed by means of the wedge K and screw L acting on the toggle block M, and provides for the rocking lever moving laterally so as to enable long or short toggles being fixed between it, the swinging jaw, and the toggle block. Rollers are substituted in the more recent machines for this purpose with a view to reduce the friction and wear of these parts to a minimum. A positive drawback movement is obtained by the rod and chain N fastened at one end to the through bolt N¹, which also retains the jaws in the jaw stock in proper position, and prevents them from becoming loose. The chain portion of the drawback arrangement passes over a pulley N², the other end being fastened to a pin in the rocking lever. This pulley is kept taut by means of a forked attachment screwed at one end, and attached at the other by a bolt and nut to the pulley. The screwed end passes through a cross-bar of wood O, strengthened by a thin steel plate, which fits into a recess at the end of the frame, the whole attachment being regulated by a handle P. The cross-bar O is purposely made elastic, so that any undue or accidental strain transmitted to the mechanism may be instantly relieved by its yielding to that strain. It will be apparent that by this arrangement the movements are all in one direction and the reciprocating parts thoroughly balanced, which in actual working saves motive power, while breakages are practically unknown when the machine is kept in efficient order. By having a positive drawback movement the undesirable india-rubber spring is dispensed with, an arrangement common to most other stone-breaking machines, which absorbs a considerable amount of power in compressing the spring to the extent required for returning the swinging jaw after the completion of its stroke.

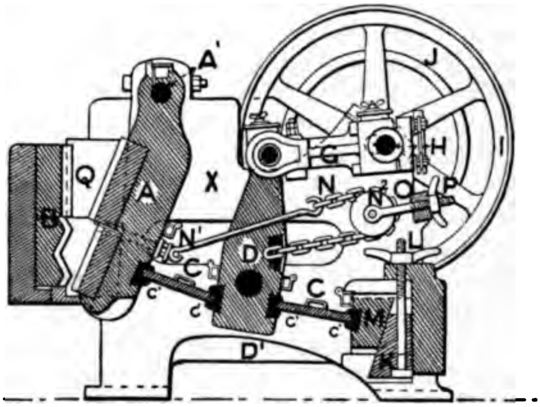

Fig. 107.—Sectional elevation of Baxter's stone-breaking machine.

It will be observed that the toggles working in the toggle bearings c¹, and operated by the rocking lever through the shaft, provides an intermediate arrangement between the driving shaft and the jaws for breaking the stones. At the same time great irregularity of movement is given to the jaws by having compound toggles, and this also gives the most powerful and direct blow possible to the reciprocating or breaking jaw.

The teeth in the swinging jaw stock are made straight from top to bottom; the upper ones, 3½ inches apart, project beyond those below them; on the face of the upper fixed jaw the teeth are also projecting, but the teeth of the lower fixed jaw are made with four bends, as shown in section in fig. 107, and are spaced 2½ inches apart, so that their ridges work into the furrows of the teeth on the opposite jaw. The large vertical space provided by this means, and the fixing of the upper jaw in the swinging stock so as to project over the lower one, enables the material which is sledged by the upper jaws to be altered in position relatively when passing through the lower or cubing jaws.

This arrangement produces a more cuboidal sample of macadam and less waste than when the teeth of all the jaws are continuous and straight from top to bottom, or where unnecessary variations of form are introduced in all the four or more jaws usually employed. The fixed jaws are retained in position by means of side wedges Q, those in the swinging stock being run in with white metal and further secured by means of through bolts. Considering the amount of work done by the jaws there is considerable wear, and various kinds of metal have been tried, such as manganese-steel, in order to produce better and more economical results. The latest description of material for this purpose is known as 'Knaponised' castings. It is admitted this material is superior and can be produced at less cost. The bearings, where necessary, are provided with brass bushes; the shafts and other important parts are well protected, and give little trouble in actual working. Special means are provided for properly lubricating the working parts; this demands great care in order to prevent the admission of dust to the bushes and shafting, which, if permitted, would quickly wear out these parts.

The framework for carrying the screens, elevating belt, and delivery-shoot, is shown in front and end elevations in figs. 108 and 109. The breaking machine mounted on wheels, with the fixings employed for retaining it perfectly rigid while at work, and feeding platform, are also illustrated.

The principal part of the framework is made of channel irons *a*, fixed on each side of the main frame of the machine; and extending to the rear of it a sufficient length, accommodates the lower revolving screen *b*, the drum *c* for the elevating belt, and the necessary gearing for operating them. On these channels an open framework of iron bars of different section is erected as shown in figs. 108 and 109; these carry the pedestal bearings *d* for the screen *e*, elevating belt *f*, and also the delivery and return shoots *g* and *h*. The lower revolving screen is fixed on two 'spiders' which are keyed to the shaft *b'* running through them; this shaft revolves in a bearing *i* on the front of the machine, while at the other end it runs in a pedestal bearing *j* fixed to the iron cross-bearer *k*, which also secures the channel irons together at a fixed distance apart. This shaft likewise carries the hollow drum on which the elevating belt gyrates, and to which it is properly keyed. The revolving of this screen is provided for by means of a bevelled wheel *l*, fixed on the rear part of the drum in which a pinion *m* works at right angles to the shaft *b'* of the screen. The spindle *n* on which this pinion is keyed revolves in the pedestal *j* carrying the lower screen and shaft, while at the other end it runs in a bush attached to one of the channel irons, on the end of which is keyed the pulley wheel *o*; it is also connected by a driving-belt to the cone *p*, on the fly-wheel shaft *h*, so as to actuate the mechanism connected with the lower screen.

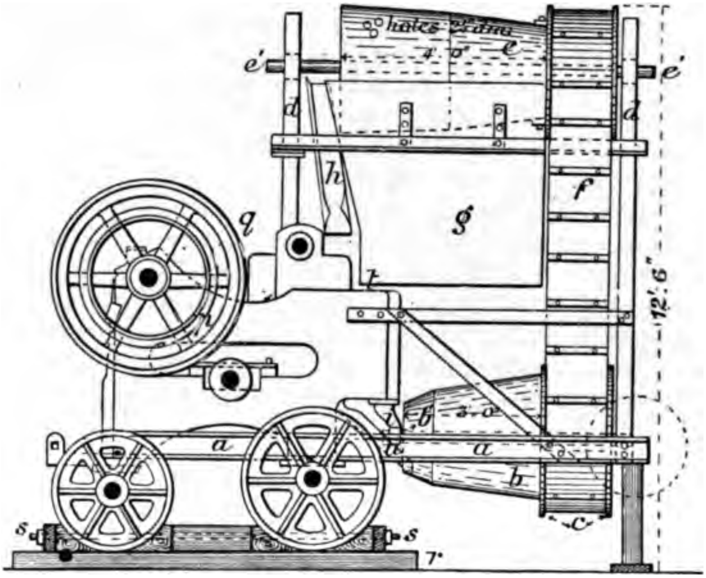

FIG. 108.—Front elevation of Baxter's stone-breaking machine.

The top revolving screen and drum are fixed in a similar manner; the shaft *e'*, which carries them, runs in two upright pedestal bearings *d*, which rest on, and are fixed to, the top of the bracing and bracket pedestal as shown in the figures. Wooden blocks are usually inserted between the brackets and the parts carrying them; these can be raised or lowered by wedges in order to accommodate the elevator belt to the varying atmospheric conditions. This means of raising or lowering the top screen, and consequently regulating the length of the elevator belt, can only be carried out when the machine is at rest, and may probably necessitate, should a sudden change in the temperature take place, stopping the machine to rectify this, which would involve a loss of time.

223. Lifting Arrangement for Top Screen.—The author has adopted an arrangement which prevents this delay, and also ensures the shafts of the lower and of the top revolving screens being maintained at their proper distance apart while the machine is working. This device, which is very efficient for the purpose intended, also maintains the pedestals and shaft of the top revolving screen perfectly rigid; it is constructed and operated in the following manner.

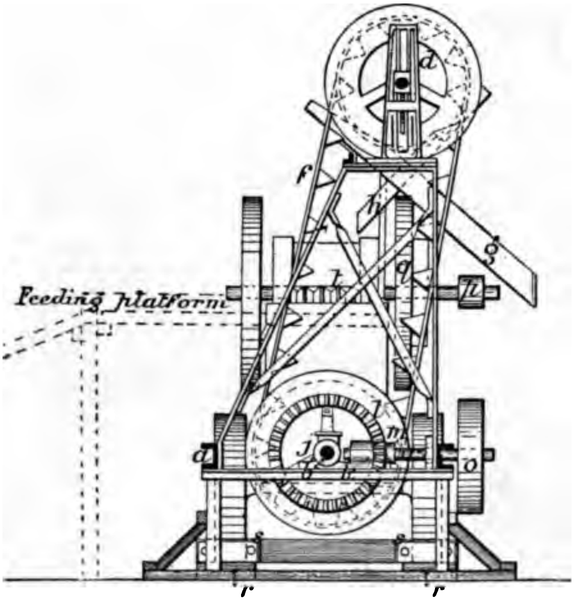

FIG. 109.—End elevation of Baxter's stone-breaking machine.

Two pedestals, *d*, are made in the form shown in fig. 110, and are bolted permanently to the top of the framework at one end, and to the bracket at the other end. Two metal blocks, fig. 110, occupy the central or open portion of the pedestal, that at A being fixed, while provision is made for the screw C working through it vertically; the block B carries the end of the shaft of the revolving screen in each pedestal, and is arranged so as to slide in a recess on either side, which secures its position horizontally. When

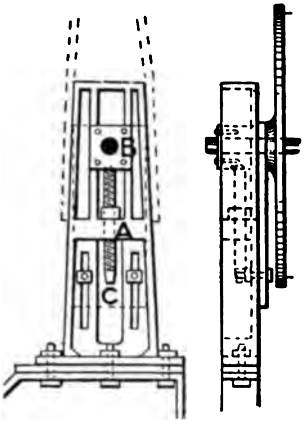

FIG. 110.—Details of lifting and lowering arrangement as applied to Baxter's machine.

the breaking machine is not working, the block B, carrying the top screen and drum over which the elevating belt works, is lowered towards the fixed block A, by means of the screw operated by a key. Before starting work the top screen is raised at each end sufficiently high to make the elevating belt taut; the further regulating of it being carried out during the day when found necessary. By this means the shaft of the revolving screen can be kept perfectly level, which is a considerable advantage, and ensures the elevating belt working properly on the drum, thereby saving unnecessary wear.

The expansion of the india-rubber elevating belt varies according to the heat prevailing, and is considerable at times; a rise of 1 inch in the sliding-block B will represent fully 2 inches in the length of the belt.

224. The elevator belt consists of india-rubber sheet 4 to 5 ply in thickness, 16 inches broad and about 26 feet long, an allowance being made for joining the two ends by overlapping. The lifting buckets are spaced about 12 inches apart on the inner side of the belt, and are attached to it by means of plates and bolts which work between the flanges of the drums. The actual wear caused by friction on the drums is provided for by attaching strips of india-rubber sheeting about 3¼ inches wide, close to the outer edges of the inner side of the lifting belt, and against the sides of the buckets.

The portions of the elevating belt between the buckets are protected by narrow plates or by sheet iron properly attached to it.

An improved form of elevator belt is now made which is non-stretchable in comparison with those made of india-rubber. It consists of steel strips overlapped; a strip of the same material runs round the whole length at both edges, and in addition india-rubber sheeting 3 in. wide is placed outside and inside and bolted together. Strengthening plates are provided on the belt where the buckets are fixed. Steel woven wire may also be used for this purpose. A bracket carrying a small roller wheel is fixed on to the cross-bar; this prevents the elevator belt coming into contact with the frame. An arrangement on the bracket, working in a slot, admits of the roller wheel being moved in a horizontal line so as to permit of the belt being made tight or slack when necessary. By this arrangement the lifting apparatus described on p. 209, and shown in fig. 110, can be dispensed with when this improved belt and accessories are used.

The 'top drive' arrangement shown in fig. 111 is a decided improvement on the older form, as by its adoption the top screen is driven direct from the pulley on shaft of breaking machine. By this method of actuating the screen the belt and gearing are removed from the lower part of the machine, where they were subject to damage, and caused delays through carts and wagons coming into contact with these parts. The wear and tear is also minimized by reason of the great amount of dust prevailing at the lower back end of a breaking machine.

The upper part of the delivery shoot *g* is fixed to the cross-bar, and, by another bar of iron formed as a strut, fixed to the main frame of the machine and to one of the vertical bars. The shoot is provided with sides and if necessary with a division in the centre for retaining the different sizes of macadam separately; it is also fitted with a hinged door for storing a limited quantity of metalling during the interval between the departure of the loaded carts and wagons, and placing in position those which are about to be loaded. The return shoot *h* is placed so that any rejectors, or pieces too large to go through the holes in the top revolving screen, fall into it and are carried back to the jaws of the breaker.

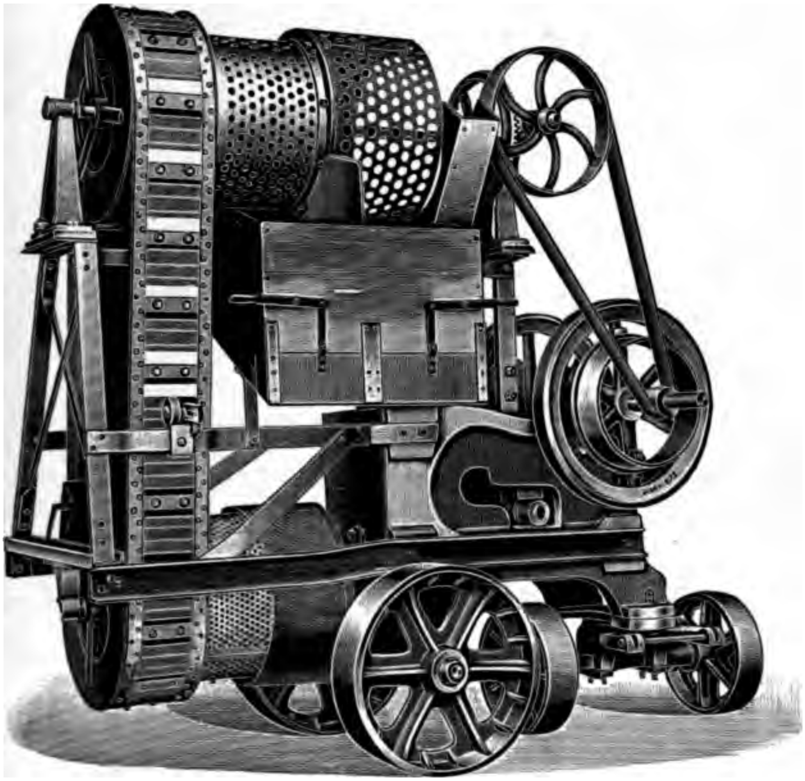

FIG. 111.

225. Motive Power to drive Stone-breaker.—The motive power required to drive this class of stone-breaking machine, including the automatic lifting and screening arrangements, is generally provided by an 8 h.-p. (nominal) traction or road-engine. Where a permanent breaking plant is erected the driving power is invariably supplied by a stationary engine under a suitable building to protect it from the weather and dust from the breaking-machine. The power required to drive Baxter's stone-breakers may be taken at 1 h.-p. nominal for every ton the machine is guaranteed to break per hour. The cost of a plant similar to that described in the foregoing sections is £305.

The removal of the breaking-machine from one quarry or depôt to another is generally performed by the same engine which drives it when breaking. Road-rollers, however, may be at times made use of for this work.

226. Setting and Working a Stone-breaking Machine.—When the stone-breaking plant arrives at the quarry where operations are to be carried on, it is necessary, in the first instance, to place the road wheels of the breaking machine on planks, previously levelled horizontally and transversely. The site for placing the planks, and consequently the position of the breaking machine, should be selected so as to be situated centrally in relation to the heap of quarried rock to be broken. By giving this matter attention the length of the 'barrow runs' may be equalized, which will result in the cost of wheeling being reduced to a minimum. The wheels of the machine should be properly secured, so that there will be as little movement as possible caused by the machine when working. By referring to figs. 108 and 109 the usual method of attaining this end is illustrated.

The two planks *r r*, 12 inches by 6 inches and 10 feet long, after being properly levelled, are so spaced as to ensure that the travelling wheels will rest on them centrally. Wooden blocks 11 inches by 5½ inches, generally made in one piece, are placed on each plank between the front and rear wheels and properly formed at either end to fit the curvature of the flanges of the wheels. Two other sets of blocks, but curved at one end only, are placed in position against the front and rear wheels. Two planks, 11 inches by 3 inches, provided with ½-inch iron plates, are then placed one in front and the other at the rear. These plates serve the purpose of washers attached to the outside of the planks opposite the wheels, and should be sufficiently long to admit of the through bolts placed on either side of the wheels being properly embraced by them.

All the blocks and cross planks are kept rigidly in position by four through or side bolts 1 inch in diameter, one being placed on either side of each of the wheels and provided with screws at either end; this arrangement lends itself to speedy handling, while all the bolts are firmly secured by nuts.

The rear end of the framework at the elevating belt requires to be supported and made as rigid as possible; this is readily accomplished by means of two planks with uprights between and tied together, or they may be braced as shown in the end elevation, fig. 109.

The feeding platform is erected by fixing a few uprights about 5 feet clear of the framework; these are placed on the opposite side of the machine on which the delivery-shoot is attached; the cleading, which forms the floor resting on the cross bearer of the iron framework, is fixed immediately below the level of the mouth of the machine. Side pieces of timber are fixed round the feeding platform to prevent any stones falling into the working parts of the breaker, while the top of the cleading is sometimes covered with iron plates; this precaution preserves the planks, which are otherwise quickly worn through by the incessant dumping of stones on it, and by the subsequent shovel work in transferring the material to the jaws of the machine. Barrow runs are then arranged, having easy gradients from the quarry floor to the feeding platform, the sledged material being generally wheeled to the machine by four men, but when the distance is considerable five or six men may be required for this work. If the stone-breaking machine has been placed at a suitable point in relation to the quarried rock, a less number of men will be necessary to wheel the material to the feeding platform than when the site has been selected to suit other minor considerations. Before the actual breaking operations are commenced, the machine should be run while empty for a few minutes to ascertain if all the working parts are in proper order.

The feeding of the material into the jaws of the machine, *t*, figs. 108 and 109, is performed by two men, who place the large pieces of rock into it by hand, and the smaller material by shovels, so as to keep up a steady and constant supply of stones in order that the capacity of the breaker may be utilized to its full extent, without overstraining or choking taking place. Stone-breakers, into the jaws of which the material is shot or tipped in a promiscuous manner, do not produce macadam so well cubed as when hand-fed; by the latter means the rock can be placed in the machine with due regard to its line of cleavage, while the amount of screenings is considerably less than in the former method of feeding. The material, after passing through the jaws of the machine, is conveyed by means of a shoot *u* to and passed along the lower revolving screen *b*; the dust, chips, and gravel deposited underneath are removed and placed in separate heaps at some convenient point for future use. The actual macadam, including the rejectors or large pieces of stone, and which should form a fairly large proportion, are delivered into the elevating belt and buckets *f*, and then conveyed to the top drum, where the material is discharged into the top revolving screen *c* by means of a shoot.

227. The maximum size of the macadam will be determined by the diameter of the holes in the top screen; any stones exceeding that size must necessarily pass to the end of the screen, and, falling into the rejector shoot *h*, pass through the jaws of the breaking machine again. By opening the jaws somewhat wider than is necessary for the size of the metal aimed at, especially when breaking rock of a brittle nature, the best sample of macadam will be obtained, and a less percentage of screenings be produced.

In quarries where the breaking machinery is placed in a permanent position, and especially where more breakers than one are employed, the material from the quarry face is generally transported to the breaking machines by means of bogies. The tram-roads are laid to and adjoin the feeding platforms; these platforms are inclined towards the jaws of the machine on to which the rock is tipped; one man guides and regulates the material into the mouth of the machines with an iron rod. Under such circumstances the stone-breaking machines are generally (at all events those used for sledging the rock) of a comparatively large size, so that careful feeding is not so important as in smaller machines. Before detailing the amount of work done by a stone-breaking machine and the cost of production, it will be necessary to explain the means adopted in removing and replacing the jaws when they become worn, and the arrangement employed by which the top revolving screen is removed when necessary in transferring the machine from one quarry to another.

The crane arrangement for lifting out and replacing the jaws consists of two T-iron uprights fitted into recesses, and bolted to the framework on either side close to the position occupied by the jaws. At the upper end a cross-bar on edge is fitted, and a hook with block and tackle attached for lifting and lowering the jaw stock and fixed jaws. The renewing of the jaws in the jaw stock requires careful attention, as, should the white metal not be uniformly run in and around the jaws, breakage may take place when at actual work.

228. Removing Top Screen when Travelling.—The top revolving screen should for convenience and safety be unshipped when removing the machine from one quarry to another, especially in thickly-wooded districts and in places where the service roads are tortuous and rough. The process of lowering it down by means of ropes and planks is not wholly free from danger,

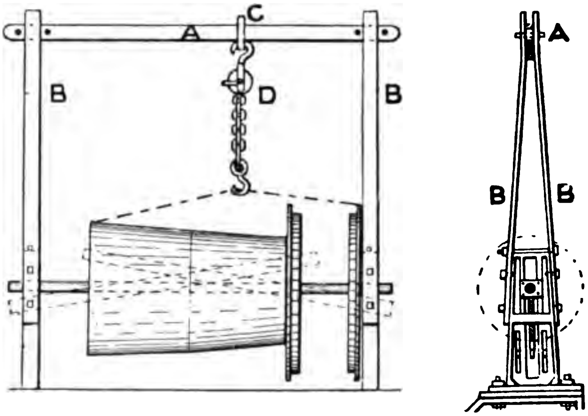

FIG. 112.—Baxter's machine; mode of removing top screen.

while the time occupied in either lifting or lowering the screen is considerable. A simple means adopted by the author for this purpose consists of two iron standards bolted to each pedestal block, as shown in fig. 112. A cross-bar A with check studs is fitted into a recess of and extends between the standards B; the hook C on this bar is attached to the block and tackle D. The standards and cross-bar require to be of such height that when the lifting block is attached there will be ample space for the top of the screen clearing the cross-bar and the ends of the shaft becoming disengaged from the sliding blocks in the pedestal bearings. When travelling, the height of these standards would in most cases prove inconvenient; provision is, therefore, made for the removal of one of the stud bolts on either side, so that each standard can be folded over inwards to the level of the pedestal block and secured in that position, as shown by the dotted lines in the illustration.

229. Quantity of Macadam broken and Cost per Ton.—The amount of rock reduced by sledging to a proper size, namely, 16 inches by 9 inches, which a stone-breaking machine of the size described can break in one day, will depend on the nature of the rock operated on and the number of hours the machine is at work, while the climatic conditions also enter largely into the question of the actual performance of the machine. Taking an average, based on an experience extending over a considerable number of years, the author finds, taking all classes of 'whinstone' into consideration, that it amounts to from 64 to 68 tons of macadam broken in nine hours. The amount of chips and gravel produced will necessarily vary according to the nature of the rock, and the percentage may be as high as 5 cwts. per ton of rock broken, while with material of a tough nature the amount of screenings may only be 3 cwts. per ton. The weight of the chips and gravel is ascertained occasionally, so as to fix the proportion of screenings to macadam. The average, however, may be taken as 3½ cwts. per ton of rock broken, which will make the inclusive weight of material broken by one of Baxter's 16 inch by 9 inch automatic and screening machines from 75½ to 80 tons per day of nine hours. This may be taken at 8½ tons per hour, but under favourable conditions from 80 to 90 tons of metal may be broken each day. During a period of forty-eight days in one of the quarries under the author's supervision the total quantity of metalling broken was 4032 tons, or equal to 84 tons per day of nine hours. The amount of the screenings, consisting of chips and gravelly material, is generally in excess of the requirements in most districts. It will be more conclusive, therefore, in arriving at the cost of producing macadam, to calculate the price of the material actually applied to the roads for renewal or maintenance purposes.

It may be mentioned, in passing, that the chips and gravel afford an excellent material for binding in connection with rolling operations, and when thus employed, or made use of for repairing footpaths, the value of the material used should be credited on the side of breaking.

For the purpose of determining the cost of producing macadam by means of a stone-breaking machine, the actual or serviceable material which can be applied directly to the roads will be considered first.

TABLE XXV.

Cost of breaking macadam by machinery.

	£	s.	d.
Engineman, ...	£0	4	0
Coals (steam navigation) for stone-breaking machine, 6 cwts., including carting an average distance of 2 miles, at 12s. per ton, ...	0	3	8
Carting water for stone-breaking machine, one-third day of a horse at 8s., ...	0	2	8
Foreman of breaker, ...	0	3	8
Feeders, two men at 3s. 6d., ...	0	7	0
Barrowmen (performed by contract at 3d. per ton on 77 tons of rock), ...	0	19	3
Removing chips and gravel, two men, ...	0	6	8
Lubricants and waste for engine and breaker, . . .	0	1	3
Allow for time lost in removing plant from one quarry to another once in three weeks, one day of whole squad,	0	2	6
Depreciation on engine and repairs, including sleeping van and water cart, ...	0	4	0
Depreciation and repairs on stone-breaker, including renewal of jaws, lifting belts and buckets, screens, etc.,	0	3	0
Costing of breaking per day, . . .	£2	17	8

This is the actual expenditure, including depreciation on one day's work. If 66 tons of macadam be taken as an average day's breaking, the cost will be 10·48d. per ton.

This is increased beyond the actual working expenses by the necessity of recording the weight of the broken material, which is performed immediately after breaking, and before it is removed to the roads under repair. This is effected by means of a portable steelyard, such as Pooley's agricultural type of weigh-bridge, the parts of which are easily put together or removed; it is of a light but strong construction, and can be readily adjusted. The cost of weighing the macadam, including depreciation and repairs of the machine, may be taken at 3s. 2d. per day, or equal to 0·58d. per ton. This additional expenditure may not be absolutely necessary, but it is advisable to ascertain exactly the quantity of macadam broken each day. When the haulage of the metalling from the breaker to the highways is performed by contract, it becomes indispensable to weigh the macadam.

There are other circumstances which have also to be considered in arriving at the ultimate actual cost of producing macadam by means of a breaking machine, as, for instance, the inclement nature of the weather or a breakdown. In the latter case, if the machine is kept in an efficient state of repair and properly managed, the loss by such a possibility is very small indeed. In the former case it will depend entirely on the weather, and as the leading hands are paid full time even during delays caused by wet weather or otherwise, it is necessary to allow a sum to cover this loss. The experience of the author is that an amount equal to 0·32d. per ton will be ample to meet such a contingency. These items summarized represent the actual cost of preparing macadam delivered into carts or wagons under ordinary conditions, and are as follows:—

TABLE XXVI.

	Pence per ton.
Cost of breaking macadam,	10·48
Weighing macadam,	0·58
Contingencies,	0·32
Total cost,	11·38
In the event, however, of a quantity of chips and gravel being utilized in rolling or for other operations, a sum equal to say 50 per cent. of the value of the total amount of screenings should be deducted, amounting to,	1·24
Total cost after deduction,	10·09

The cost of labour and the fuel for the engines have a bearing on the total cost per ton of macadam broken, and may vary considerably in different counties and districts. The author has on many occasions accomplished this work for 9d. per ton (but the inclusive cost has generally been 10½d.) by arranging the work to be carried out during the most suitable months of the year. If the working expenses incurred be calculated on the total amount of rock broken each day, then the cost, taking the quantity as 77 tons, would be 9d. per ton.

It is of importance that the working parts be kept in good order, so that unnecessary delays may be avoided. Should the amount of metal broken each day be reduced in quantity, through delays or breakdowns, to, say, 45 tons, then the actual cost of production will be increased. In the case instanced the cost would be 1s. 2d. per ton. Referring to par. 229, p. 215, the cost of producing the macadam during the period stated amounts to 8½d. per ton of metal broken.

On referring to p. 195 it will be seen that the comparative cost of hand-broken macadam is 1s. 3d. to 2s. 6d. per cubic yard, or 1s. 1½d. and 2s. 3d. per ton respectively. The average, however, may be taken at 1s. 9d. per ton, which represents the price paid for this class of work previous to the introduction of stone-breaking machinery into the district of which the author has charge; but it may be incidentally remarked that the price for hand-broken macadam is now much higher. The difference in the cost of production between hand- and machine-made macadam is therefore, taking 11d. per ton for the latter, nearly 48 per cent. in favour of macadam produced by a stone-breaking machine. It may be mentioned here, although the matter will be described fully in the chapter on 'Rolling,' that the macadam produced by a breaking machine, being properly screened, makes a much superior road surface compared to that which can be made with unscreened hand-broken metal.

If hand-broken metal be screened so as to improve its wearing capacity, then the saving in favour of macadam produced by machinery will be still greater.

230. The requirements of a district or county in regard to the quantity of macadam required for maintenance will depend in a great measure on the amount of traffic, the quality of the material used, and the mileage of roads to be repaired each year. When the quantity does not exceed 8000 or 10,000 tons each year, one stone-breaker of the construction and size described will accomplish this in from seven to eight months, allowing for the time lost by occasional wet weather and other causes. If the quantity of metalling required each year exceeds these figures, it will be more economical to employ two or more machines, so that the total quantity necessary for repairs may be broken during the summer months. One stone-breaking machine working during the whole year in different quarries will be capable of producing, in addition to the 8000 tons already mentioned, a quantity during the other four or five months of the year of from 3500 to 4400 tons, or a total for the whole season of from 12,400 to 13,500 tons of macadam.

The cost of production during the winter months will be increased considerably, and in many instances may exceed the cost of breaking the material by hand during the summer months.

This does not apply, however, when fixed machinery is employed, where the work is carried on during the whole of the year, although the cost is sometimes increased by working on a short day, or even on full time at that period of the year when using the electric or other light. Under these circumstances it is usual to erect a covering over all the stone-breaking plant in order to afford shelter for the men engaged, and so admit of the work proceeding without interruption. This also protects the machinery during unfavourable weather.

231. Amount of work performed by working parts, and Cost of Renewals.—The wearing parts, namely, the jaws, wedges, toggles, and toggle bearings, lower and top revolving screens, elevator belt and buckets, etc., are easily renewed; their life of usefulness will depend on the amount of work performed, the nature of the rock broken, and on the care with which the different parts of the machine are attended to.

Taking an average over many years, the more important parts mentioned will, depending on the quality of the material used in their manufacture, perform approximately the following work before the necessity arises for renewing them.

TABLE XXVII.

	Tons.	Cost.	Cost per ton.
		s.	d.
Upper jaws (reversible), . . .	8,000	44	0·066
Lower jaws (reversible), . . .	4,000	44	0·132
Top screen, plates ½ in. thick, . .	24,000	120	0·060
Lower screen, ...	48,000	90	0·022
Elevator belt, 5-ply, plates, etc., .	32,000	240	0·090
Buckets, set of 25, ...	8,000	40	0·060
Toggles and bearings, side wedges, etc., 1 set, ...	8,000	55	0·082
			0·512

232. The top revolving screen of the stone-breaker is usually constructed so as to produce two different sizes of macadam, and a division in the delivery-shoot provided for this purpose enables each class to be removed at will.

By this arrangement the smaller-sized macadam can be used for patching or for coating the hilly parts of the highways, but it is seldom the case that both sizes of macadam can be utilized and consolidated separately on the same road.

It therefore becomes necessary to store one or other class of macadam, which, on economical grounds, should be avoided as much as possible. This will be apparent when it is considered that to store and refill road metal an expenditure of from 3d. to 5d. per ton is incurred.

It is more usual, however, to have different sets of top revolving screens having perforations of a size suitable for the work on hand, so that the total amount of macadam broken may be removed direct to the roads under repair. For this purpose a top screen having holes 2¼ inches in diameter will suit the requirements in most instances.

The stone-breaking machine (Baxter's 16 inches by 9 inches) which has been described fully in the foregoing pages is the only practical machine, so far as the author is aware, combining the simplest form of construction for the efficient operations of breaking, screening, and loading. The detailed amount of work which can be accomplished by its use, and the working expenses involved in the production of macadam, are such as will compare favourably with any other make of machine for similar purposes, while the motive power necessary to work it is considerably less than in the case of most of the other stone-breakers.

233. Marsden of Leeds and Mason of Leicester make a form of screening and loading machine, which is so arranged that all the material broken is elevated overhead to the top revolving screen, where the dust, chips, and macadam are separated. In working a breaking machine with this arrangement it is obvious that the dust treated at such a height will be blown in every direction during the prevalence of wind, causing great inconvenience to the men engaged in working the machine. The increased carrying capacity required for the elevator belt will necessarily involve a greater motive power to overcome the friction caused by this additional weight of material being raised.

234. The Hadfields' Steel Foundry Company, Sheffield, have recently introduced a rock and ore crusher known as the 'Heclon.' This type of crusher is similar in principle and appearance to the Gyratory Rock and Ore Crusher described in par. 235 and shown in fig. 113. Many improvements have, however, been introduced in order to minimize the excessive wear and the number of breakages incidental to this description of machine. This firm also make the general type of stone-breaker described by some as jaw crushers. Manganese-steel enters largely into the castings of these machines, where such material can be beneficially utilized.

235. A great variety of the jaw type of stone-breaking machines are in use in the United States and other countries, all more or less constructed on the same principle as the original Blake. One form of stone-breaker differing widely in the principle of construction and working from the type of machines known in this country has, it is stated, been performing record work in America.

Gates' 'Stone Crusher.'—This machine is known by the name of the 'Gyratory Rock and Ore Crusher,' and is manufactured by the Gates Iron Works of Chicago. As the name implies, the mechanism is such that the 'crushing cone,' fitted on to a vertical or main shaft with a certain amount of eccentricity, impinges during its gyration against the material to be broken, and also approaches to and recedes from the sides of the enclosed cylindrical shell. The necessary power for operating the crusher is transmitted by bevel gearing and pinion, and is driven direct by a belt and pulley fixed on the counter-shaft.

It works without the intervention of fly-wheels, such as exist in the other types of stone-breaking machines, and it is claimed that under working conditions there is little or no vibration.

It is of simple construction, and has few working parts. The strain on the gearing, however, when running at a high speed, must necessarily be very great, from which it is reasonable to suppose that great wear and tear and occasional breaking of these parts will take place. This machine, although specially designated a 'crusher,' would appear, from the construction and movement of the working parts, to create a sliding motion which would naturally subject the material to crushing. This, however, does not occur to any great extent in actual practice, the machine turning out a very fair sample of macadam.

A vertical section of the gyratory machine, known as the 'D type,' which is the latest form of crusher made by this firm, is shown in fig. 113 fixed on a timber foundation.

The principal parts of the crusher may be described as follows:—The shaft A is held rigidly at the top in the spider J, while it is gyrated by means of the bevel gearing-wheel D, the bevel pinion E, the counter-shaft F, and the pulley G. The eccentric B admits of the shaft carrying the crushing head or truncated cone C approaching to and receding from the shell H. Inside the latter the concaves I are fixed, by which means the cone impinges the rock against the concaves. The material to be treated is dumped into the feeding hopper K, and after being broken leaves the machine by the shoot L, to be elevated to the sorting sheds or screened under the foundation on which the machine rests. In the former case the whole of the broken material, of varying sizes, is distributed by conveyors into separate bins for immediate removal, or stored for subsequent use.

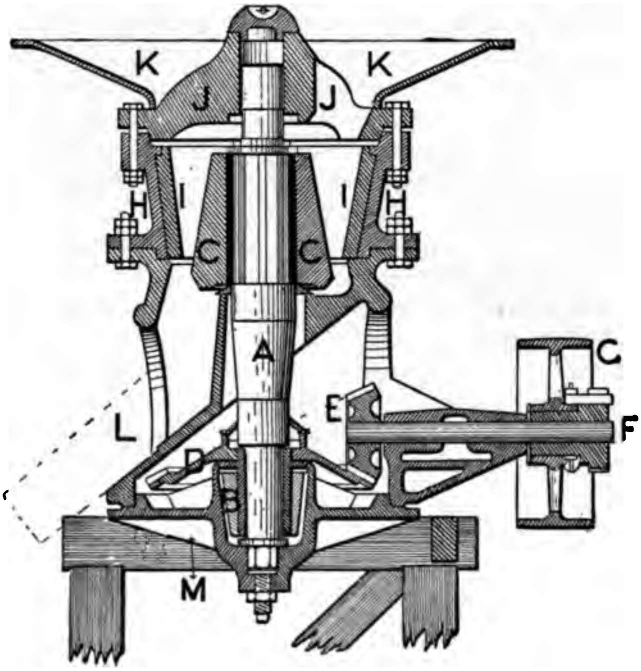

FIG. 113.—Gates' gyratory stone-crusher (sectional elevation).

The foundation for this type of crusher may be of timber, mason work, or concrete, to which the bottom plate M is fixed. This class of crusher is made in different sizes, and is calculated to break from 2 tons per hour with a No. 0 machine, requiring 4 h.-p. (indicated) to drive it, up to No. 8, which is intended to break, according to the nature of the rock, from 100 to 150 tons per hour, requiring an engine with an indicated h.-p. of from 100 to 150 to drive it, including the screening and elevating arrangements.

The price of the No. 0 machine is £75, and that of the No. 8 £1400, which figures do not include the cost of the necessary foundations. This type of stone-crusher has not, unlike most other American inventions, been extensively used in this country yet. The only recorded trial of their working, of which the author is aware, was that in open competition with a Baxter's stone-breaking machine at the Bath and West of England Show held at Bristol in June 1886. The stated capacity of the gyratory crusher (No. 5 machine) was 40 tons per hour, and it was driven by a 10 h.-p. engine, but the actual quantity of macadam produced was only at the rate of about 8 tons per hour. The other stone-breaker, Baxter's 16 inches by 9 inches, guaranteed to break 8 tons per hour, actually broke at the rate of 12 tons per hour, and was driven by a 6 h.-p. engine. An extensive plant of the gyratory type has been recently laid down at the granite quarries near Dalbeattie, Kirkcudbright, and has also been introduced at Hartshill quarries, Leicestershire, and at Alderney, in the Channel Islands. It will be interesting as well as instructive to follow the actual performance of these machines on a class of rock similar to what the type of stone-breaking machines used in this country are accustomed to break into macadam, of which the quantity broken in a stated time and cost of production are known.

Haulage.

236. The hauling or conveying of macadam from the breaking machine or quarry to the section of road under repair may be performed either by means of team labour or by traction-engines and wagons. Team work may be paid for at so much per day for each horse and cart, but is generally contracted for at a price per ton-mile, or, in other words, by results. The former method may answer to a limited extent under certain circumstances, but is not economical.

237. **Cost of Haulage.**—The cost of haulage is arrived at by taking the total quantity of macadam carted direct from the stone-breaking machine to the road, where rolling operations are being carried on, or in the case where the surface repairs are executed on the patching system, to the road-side depôts, and the price per ton at the average distance. The average cost is determined by the price per ton-mile, and the distance from the quarry to a point midway between the nearest and the furthest points of the road upon which the macadam is applied. This work is best performed by contract, the conditions generally being that tip-carts only are to be employed,

and that the quantity of material which must be transported each working day is stipulated, according to the breaking capacity of the machine employed.

238. Number of Horses and Carts required.—The varying conditions of the work necessitate the employment of a greater or less number of carts during the progress of the rolling operations, depending on whether the distance is considerable or otherwise to which the macadam is to be conveyed. The number of horses and carts engaged will also depend to a certain extent on the nature of the service roads over which the material is to be conveyed. When a quantity equal to 23 or 24 cwts. of macadam is removed by one horse each trip, allowing from eight to ten minutes for loading, the average number may be taken at six carts for every mile of travel from the quarry or depôt to the point where the macadam is to be deposited. For instance, if the metal is to be applied at a distance of 1½ miles from where the breaking operations are being carried on, nine carts will be necessary; should the distance be two miles, then the number of carts required will be twelve, provided, as already mentioned, that the weight of macadam carried by each cart is as stated.

239. The Cost of Team Haulage.—The price per ton-mile for team haulage will vary according to the condition of the roads leading to and from the quarry, and whether they are hilly or otherwise of difficult access. The cost is also affected by the relative distances to which the material is carted; that is, the price for a distance of, say, one mile and upwards is less per ton than when the distance is under that mileage. This is brought about by the fact that in long journeys the horse is earning money with little lost time standing at the stone-breaker while the cart is being loaded as compared with a short distance from the quarry, as the time thus lost during a day's work will be greater, because in the latter case the horse returns more frequently to the quarry, and in consequence, by repeatedly losing time, less effective work is performed.

The cost of this work on the highways of which the author has charge, and embracing the experience of a number of years, shows that it may be taken at the following figures per ton-mile, viz.:—

TABLE XXVIII.

	Pence.
On good service and main roads, ...	8½
On do. do. but slightly undulating, ...	9½
On hilly roads with a good surface, ...	10½

The first of these prices may be further taken as representing the work done by a single horse taking a gross load of from 32 to 34 cwts. The figure 9½d. is applicable when the nature of the road necessitates the gross load being reduced in weight, and consequently the employment of more carts, or when it is necessary to provide occasional assistance in ascending a steep gradient. The figure 10½d. generally provides for assistance at one or more points, when the hilly nature of the roads would necessitate the average gross load per journey being considerably reduced in weight if such assistance were not provided at the points referred to. These prices are a fair average for team labour in country districts when constantly employed over considerable periods of time. In the case of such operations being carried on in the vicinity of large towns the cost of haulage will be higher to the extent of from 1d. to 1¼d. per ton-mile on the different figures given in Table XXVIII.

240. One advantage resulting from this method of conveying the material compared with that of steam traction, although the actual cost of haulage by team work taken by itself is much greater under most circumstances, is the convenient manner in which the macadam can be deposited on the road, which greatly facilitates the spreading of it. At the same time a more direct means of regulating the amount of haulage necessary can be accomplished as the work of renewal gradually approaches nearer to the point of supply by simply reducing the number of horses and carts. One great disadvantage with team labour is that all horses do not travel at the same pace; hence in many instances, especially in long distances, the slowest horses practically govern the amount of work done. This means less material removed, and consequent storing of the metal takes place, or the number of horses necessary must be augmented, increasing the cost.

241. Recording Weight of Macadam broken, for fixing Cost of Haulage.—The loaded carts, as already stated, pass over a steelyard, and a record of the weight is kept in a book for the purpose. The form and manner in which the weights are arranged are shown below, and a day's work is given as an example.

TABLE XXIX.

......................*Quarry*, ...19...

Weight of Empty Carts.	Contractor's Name or No. of Cart.	Number of Cart Loads and Gross Weight of each in Cwts.						Total Weight.	Total Weight of Empty Carts.	Actual Weight of Road Metal.
9½ cwts.	...or No. 1	35½	35	36¾	38	37½	37¼	220	57	163
9½ ,,	,, 2	34	33½	34¼	35	35½	36	208¼	57	151¼
10 ,,	,, 3	32½	32	32	31½	32¼	32½	192¾	60	132¾
9½ ,,	,, 4	34	36	34½	34	35	34¼	207¾	57	150¾
9½ ,,	,, 5	31¾	34½	34½	34¾	33¾		168¾	47½	121¼
9 ,,	,, 6	32½	32	31¾	32	32½		160¾	45	115¾
9 ,,	,, 7	33¼	34	33½	33½	33¼		167½	45	122½
9 ,,	,, 8	33	31½	32¼	31¼	32¾		160¾	45	115¾
10 ,,	,, 9	34¼	36½	35¼	33¾	35		174¾	50	124¾
10 ,,	,, 10	34½	34¼	35¼	34	34¼		172¼	50	122¼
									20 ÷	1320
								Tons,	. . .	66

It will be observed that the first four carts performed six trips, while the others accomplished only five, the latter of course taking the first turns the following morning, and so on, equalizing as much as possible the amount of work performed by each horse.

It will also be noticed that each horse hauled on an average 24½ cwts. of road metal, or a gross weight of fully 34 cwts., each trip, from the stone-breaker to the road under repair. The empty carts are repeatedly passed over the steelyard to verify their weight, this being done each day during inclement weather.

242. Steam Haulage.—Steam haulage by engines and wagons presents one important advantage, under certain circumstances, as a means of conveying the road metal direct from the stone-breaker to the point where it is to be applied; that superiority being economy. It is imperative, however, that a suitable access be made to the quarries for this method of transporting the macadam, that the service roads be of sufficient width and strength to carry such heavy weights, and that the work should be effected during dry weather, otherwise considerable damage to the roads may be the result. In extremely dry weather the crushing caused by the cross-bars on the driving wheels of traction engines also at times injures the surface of the roads, and this injury the author believes would be avoided by using Boulton's patent wheels or some other similar arrangement. The damage done generally to the roads by this system of hauling the material detracts to a certain extent from its usefulness as a means of rapidly and economically transporting macadam for road purposes.

The area of the quarry floor must be sufficiently large to admit of the engines working freely in removing and placing the wagons speedily in position so as to permit of as much time as possible being devoted to actual travelling.

For a distance from the quarry up to one mile where the metalling is to be deposited, one engine and three wagons are necessary to carry on the work uninterruptedly, one of these wagons being held in reserve in case of an emergency.

This may be considered the greatest distance which one engine can travel and return to the quarry in one hour, having regard to the time occupied in removing the loaded wagon and placing the empty one at the delivery-shoot of the breaker, and the time consumed while discharging the metalling on the road under repair.

Traction wagons having a capacity of fully 7 cubic yards or 8 tons would therefore be necessary with the stone-breaker described, as this is under ordinary circumstances the quantity of 2¼-inch road metal which it can break in an hour.

243. Cost of Steam Haulage.—The cost of steam haulage by wagons to a distance of one mile from the quarry is made up of the following items, all the plant being hired:—

TABLE XXX.

Cost of one day's work.

Hire of engine, two men, and three wagons, ...	£1	3	6
Coals (steam navigation), 7 cwts., 12s. per ton, ...	0	4	2
Supply of water for engine; allow proportion as only being required in certain circumstances, one-fourth of a day's hire of above, . . .	0	2	0
Man in attendance while travelling, 1 man, 3s. 4d., ...	0	3	4
Allow for trimming the metal in the wagon during time it is being loaded, 2 men, 3s. 6d., ...	0	7	0
Total cost, ...	£2	0	0

The cost of haulage up to one mile, taking 66 tons as the daily output, would therefore be 7·27d. per ton.

When the distance slightly exceeds one mile it becomes necessary, so as to avoid storing the macadam, to employ an additional engine and set of wagons to carry on the work efficiently. This at once augments the cost of haulage by fully 7d., or an inclusive price of 14·54d. per ton, immediately after passing the one-mile limit, to be again reduced to 7·27d. per ton-mile when the distance of two miles from the quarry is reached.

It will thus be evident that when the point to which the macadam is conveyed is either one mile or two miles from the quarry, the cost of hauling is at the rate of nearly 7·27d. per ton-mile, while each ton tipped on the road between the first and second mile will cost 14½d., and between the second and the third mile it will be nearly 1s. 10d. per ton. The variation in the price will be better understood when it is considered that up to one mile, which is in most cases practically the nearest distance from the quarry where the road metal can be applied, a single engine and set of wagons are fully occupied, while immediately after passing this point the two engines necessary are comparatively idle for a considerable part of the time. As the two-mile limit is approached, however, the cost per ton becomes less, as there the plant is being more fully employed again.

The cost of hauling direct from the breaking machine by an engine and wagons belonging to a County Council or Local Authority can be performed for about 1½d. less per ton at the one-mile limit, but to purchase extra engines and wagons for this purpose would not be economical, as, under ordinary circumstances, the time during which they would be occupied might only extend to seven or eight months each season. During the remaining months of the year there would be practically no work for this large plant, consequently no profitable results would accrue from the capital expenditure involved. Haulage by traction engines and wagons, therefore, can only be carried out properly and economically by those possessing the requisite plant.

244. The above arrangement is at times expedient, but it is more satisfactory to have the haulage carried out by contract. Of late years the author has had practically all the road metal conveyed by traction engines and wagons with beneficial results, apart from economy in hauling, compared with team labour. The time of the year when those engines would be idle, being partly an agricultural district, suits the work of stone-breaking, and consequently the cost of hauling is less than it would be at other times of the year, and also probably in busy centres where such plant may be employed during the greater part of each year.

The average cost is, and has been for some considerable time past, 4½d. per ton-mile, the contractor supplying the requisite number of engines and wagons for the work. Coals are supplied to the contractor, and the cost of this item is about ½d., so that the price may be stated at 5d. per ton-mile.

In loading wagons at a stone-breaker where the machine is kept at as low a level as possible, to ease the gradients of the 'barrow runs' and just sufficient to clear the wings of the wagons, it requires two men to trim the metal during loading operations. Although this work is performed in the quarry by men attached to the breaking machine, the cost will, for comparison, be debited against hauling. This makes an addition to the former figure to the extent of 1¼d. per ton, which must be included in the average cost of haulage for each day's work, when the quantity of road metal removed is as stated. The wear and tear of the roads traversed by these engines and wagons may, during wet weather, be considerable, but under normal conditions it may not be greater than by team haulage, especially when the engines and wagons are mounted on springs and travel at a moderate speed.

Contractors for hauling road-stone generally stipulate that for distances under one mile day's wages be paid, which amounts generally to about £2, 5s. A contractor can by an agreement with his men arrange that the first 'race' may be accomplished, if necessary, earlier than the usual time when the wagons are filled the previous evening, and otherwise arrange matters of mutual benefit to himself and the contracting parties.

The economical expedient of employing engines and wagons in hauling road metal is evidenced by the regular and methodical manner in which the material is, when the work is properly arranged, removed direct from the stone-breaker, thus saving the unnecessary expense of storing, inseparable, in most instances, from that of team labour. In one instance, with engine haulage, it may be mentioned that during ten weeks, breaking an average of 80 tons each day, there was not one ton of road-stone stored, and the stone-breaker was thus kept in constant working and therefore producing the material at a minimum cost. Not only is the cost of production less in the quarry, but a regular and ample supply of macadam is maintained to keep the road-roller in constant work.

Storing the macadam when no real necessity exists for such a procedure, or owing to any of the foregoing causes, ought to be guarded against, as the additional cost entailed becomes a serious matter when large quantities have to be dealt with. The interruptions necessitating storing may be only temporary, but in any case the wheeling or carting of the metalling to some convenient point where it can be easily filled into carts or wagons at some future time cannot be accomplished for less than 1½d. per ton. The loading of this stored material into carts or wagons under favourable circumstances will cost at least an additional 1½d. per ton. When the position and level of the heap of macadam in relation to the position of the carts or wagons are such that wheelbarrows have to be employed to accomplish the work, the cost of refilling may amount to from 2½d. to 3½d. per ton. Thus the inclusive cost of storing and refilling will vary from 3d. to 5d. per ton, an expenditure sufficiently great to make the conditions imperative that storing the road metal should not be permissible, unless it is done as a matter of convenience.

If this extra expenditure be included in the cost for hauling the metalling, the figures will be increased accordingly by the actual amount incurred for this work, and this expenditure is often found to have been quite unnecessary.

245. From the foregoing it is evident that it is infinitely greater economy to contract for this work, and to remove the macadam as it is discharged from the breaking machine direct to the roads. Should a plant of this description not be available, the haulage should be performed by team work; this also applies in the case where such a plant can be obtained, but where the conditions are such that economy is not promoted by utilizing steam traction as a means for hauling road material.

In counties having an available supply of suitable material for macadamizing purposes within reasonable distance of any of the roads in the district, the methods of handling the macadam just described should be adopted. In the case, however, of a locality not possessing the necessary material in the immediate vicinity, it may have to be conveyed distances varying from 5 or 6 miles up to 20 and even 50 miles. In the latter instances the road metal is most conveniently and economically conveyed by rail. In the former case, to keep a road-roller working continuously at such a distance from the source of supply would be a serious matter. In the first place the material has to be removed from the stone-breaker to avoid storing, and in the second place the roller must be fully employed in consolidating the macadam, while the two operations involve the employment of such a number of engines and wagons as may not be available in the district.

For similar reasons the employment of team work, considering the large number of carts which it would be necessary to employ in order to avoid stoppages or otherwise hamper the operations at either point, would be difficult to obtain in most districts at a reasonable cost. It would then be necessary to adopt a system of storing the material and removing it by degrees when a suitable opportunity presents itself. Although it is not an economical proceeding, as has been shown, still it is the only practical method possible of accomplishing the end in view, under such circumstances, having regard to what, under these conditions, may be the more economical method of the two to adopt in transporting the road-stones.

246. Wagons with Folding Doors and Hoppers.—In steam haulage the wagons are made with folding sides to admit of the road-stones being deposited into depôts; but, as is usually the case, the macadam is discharged direct on the road. The wagons may be provided with hoppers which admit of the road metal being deposited in a fairly regular manner on the centre or sides of the road.

To effectively carry out this the bottom of the wagons requires to be bevelled so as to admit of the stones being discharged by gravity. This arrangement, however, reduces the carrying capacity of the wagons, and any saving in this direction is compensated by a full load, even although it will cost more to unload and spread the material.

The class of plant which should find employment in this branch of road work is the heavy motor vehicles recently put upon the market. Those having an end or side tipping arrangement facilitate the unloading of the material and of roughly spreading it by controlling the swing-doors while the vehicle is travelling. These heavy motor cars, although permitted to travel faster on the highways than ordinary traction or road engines, are provided with suitable springs, and the axle-weights are regulated according to the diameter of the wheel and width of tyre. These vehicles, being of a suitable size, are easily and quickly manipulated, and therefore occupy comparatively little time in unloading. It is not anticipated that these heavy motor cars will cause so much damage as heavy road engines for a given quantity of material, although the former will have to make up in capacity by performing a greater number of journeys.

The cost of haulage by heavy motor cars has not been determined with any precision, as figures pertaining to an extended experience are not yet available. The expenses are variously stated, but on an average, taking loads one way only as in the case under review, the cost works out at 2½d. per ton-mile; this allows for ample repairs and 10 per cent. depreciation on an assumed life of the vehicle of ten years. Considering the number of stoppages each day for loading and unloading purposes, the price may be stated at 3½d., and adding 1¼d. for trimming the material in the wagons, makes an inclusive price of 4¾d. per ton-mile.

These heavy motor cars will undoubtedly prove of considerable service in connection with conveying road metal to the highways by contract at a minimum cost. It is apparent, however, that, owing to their light construction, in order to comply with the 'Regulations,' the life of these vehicles will be a short one, more especially if rough quarry roads are encountered.

The repairs, considering the amount of vibration inseparable from travelling at considerable speed on roads or streets the surface of which is irregular, cannot fail to be heavy. Notwithstanding these drawbacks, this method of transport has many points to recommend its adoption, especially in hauling material from a railway depôt over roads even in average condition.

Tipping wagons assist to a limited extent the spreading of the metal, but in every instance it is necessary, in order to properly mix the stones, that the macadam should be turned over by means of shovels before the rolling operations are commenced.

247. System adopted in the United States.—In the United States of America the work of transporting and spreading road metal is performed by horse wagons provided with a screw arrangement on the front of the vehicle, which, on being raised, causes the material to fall towards the back of the wagon, where it is discharged and distributed in such quantities as may be required. At the bottom of this distributor an adjustable iron plate, secured horizontally, regulates the thickness of the coating by being fixed at the height required above the upper surface of the material forming the bottom of a new road or the surface of an existing one.

This arrangement, the important feature of which is economy in handling the metalling, would be extremely serviceable provided the macadam composing the coating is of an equal and uniform size, but otherwise, and so long as stones composing the metalling vary in volume, even to a small extent, the work of spreading it can only be satisfactorily performed by manual labour.

CHAPTER VII.

ROAD-ROLLING AND SCARIFYING.

Road-rolling.

248.—The first important step taken in this country in the direction of advocating road-rolling by horse power as a measure of economy was set forth in a paper written by Sir John F. Burgoyne, R.E., when acting as Chairman to the Board of Works in Ireland, and published in 1843. This means of consolidating the metalling of newly-made roads was employed in that country under his directions, and may be considered the first attempt in a practical way of forming an improved road surface—not as a matter of refinement, but as a necessity. A full description of the methods followed and cost of this scientific road-rolling, which is the more valuable now, will be found in the treatise on *Roads and Streets*, by Law and Clark.*

Although it is recorded that the first allusion made to road-rolling in England was by one named Shotbolte in 1619, still the first practical horse-roller was made in France in 1787 by M. de Cessart, then *Inspecteur-Général des Ponts et Chaussées.*

It consisted of a cast-iron roller, 8 feet wide, 3 feet in diameter, and weighing 7000 lbs. (old French weight).

After repeated trials, the experiments appear to have been discontinued, probably owing to the disturbed political state in which France was at that time.

In the year 1817, Philip Hutchison Clay patented in this country a horse-roller, with a carriage over it, which could be loaded with weights varying from six to twenty tons.

Since that time horse road-rolling has been practised in this country, as well as on the Continent of Europe, to within comparatively recent years.

249. An interesting history of this subject, including steam road-rolling, is given by Mr. F. A. Paget, C.E., in a report to the Metropolitan Board of

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* Weale's Series, 197, Appendices, pp. 318, 319.

Works, 1870,* to which the author refers his readers for a full description of the early attempts in the direction of improving the highways.

The difficulties inseparable from a system of rolling roads by that means, especially when a great many horses were employed, depending on the weight of the roller, the difficulty of manipulation, and the displacing action of the horses' feet, defeated the object desired. It is not therefore surprising that this method of consolidating the metal was not practised extensively, as the results obtained did not justify the expenditure incurred.

The application of rollers to consolidate a coat of metalling, like most inventions and innovations, has been brought about by gradual evolution. The results achieved in France by the use of horse-rollers proving in a measure successful, the further improvement of the means by which the freshly-laid road metal could be effectively consolidated, led those interested in the repairs of the public highways in that country to substitute steam for horse-power.

250. The first patent for a steam-roller was taken out in France in the beginning of 1859, by M. Louis Lemoine of Bordeaux. This steam road-roller weighed ten tons, and was steered by means of gearing and a pair of guide-wheels. Besides being used on the roads at Bordeaux, it was tried in 1860 on the roads in the Bois de Boulogne, Paris, and it was improved in different ways subsequent to 1859. In August 1860, another steam road-roller was patented in France by Ballaison, and used on the roads there by Messrs. Gellerat & Co. of Paris. In 1862, experimental trials were carried out with both these steam rollers by the French engineers of state, who, besides expressing a strong opinion in favour of steam-rolling in general, gave preference to the latter machine.

In 1865 Messrs. Gellerat & Co. of Paris designed a steam road-roller; but it is stated that, owing to the small diameter and wide roller wheels, the contour of the road was destroyed and the metalling left in ridges, not smooth as it should have been; while the cost of working was excessive, the coal consumption alone being nearly 4 cwts. per hour.

251. In 1863, Mr. W. Clark, municipal engineer, Calcutta, and Mr. W. F. Batho, Birmingham, designed and patented a steam roller; this was the first attempt made to construct a steam road-roller in this country. It was made in the latter city, and sent to Calcutta in 1864.

The principal feature of this machine was the use of three sets of rollers, two in front acting as drivers, while the third or hind wheel was set in a turn-table arrangement, being adjusted so as to steer the engine and at the same time to overlap the space between the outside driving-wheels.

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* *Report on the Economy of Road Maintenance and Horse Draft through Steam Road-rolling, with Special Reference to the Metropolis*, by Frederick A. Paget, C.E., 1870.

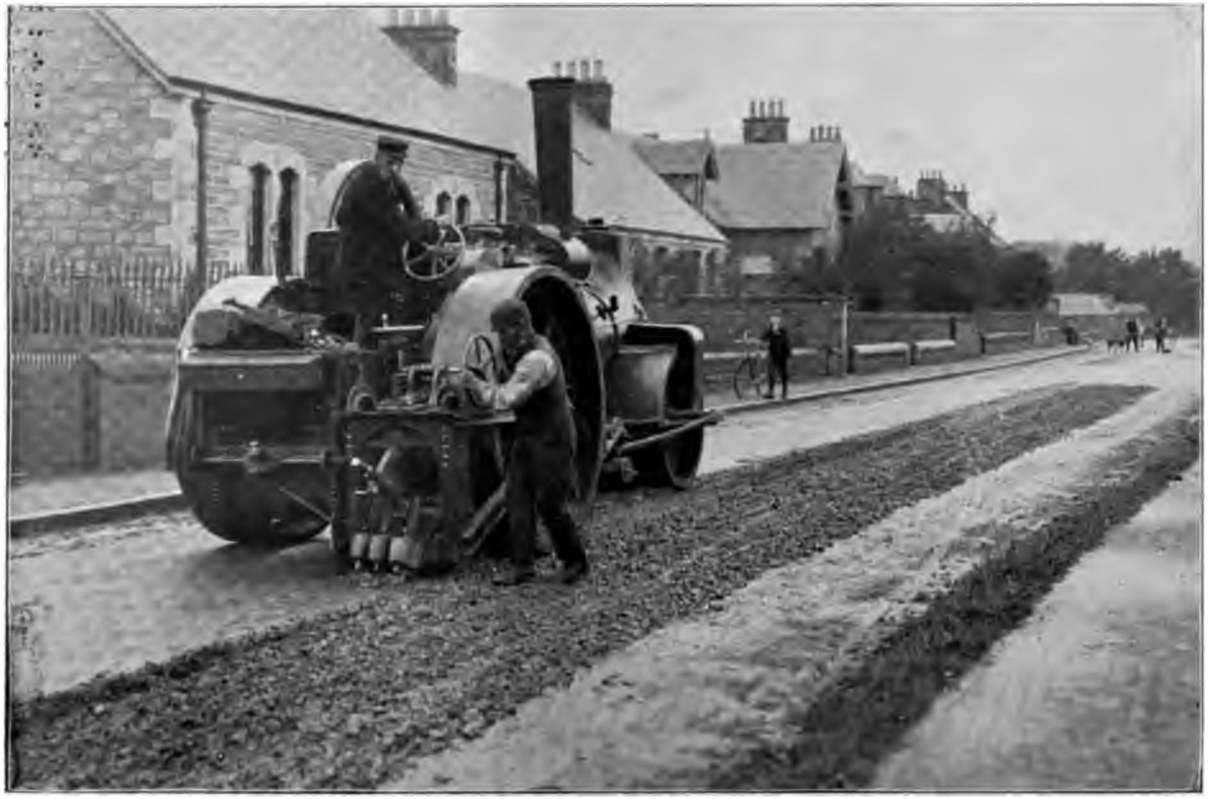

FIG. 114.—Road-roller (Aveling & Porter's) with scarifier attached. [*To face* p. 233.

Two similar road-rollers, but made by Messrs. Moreland & Sons, London, were sent out to Bombay in the following year.

Many other attempts were made about this time to obtain a reliable and economical working road-roller, and even traction-engines were requisitioned and attached to cast-iron rollers for this purpose.

252. First successful Steam Road-roller made in England.—The first successful steam roller made and set to work in Great Britain was that constructed by Messrs. Aveling & Porter of Rochester, after trials in Hyde Park, London, in 1865, with an ordinary traction-engine having broad rollers substituted for the ordinary road wheels.

The steam road-roller, shown in fig. 115, was constructed for the Corporation of Liverpool in 1867; it weighed 30 tons, and its cost was stated to be £1000.

Steam road-rolling had by this time achieved some success, and the pamphlet on the subject by Mr. Paget, already referred to, greatly popularized this means of repairing roads, many of the London vestries making trials with very encouraging results.

253. First Steam Road-roller introduced into Scotland.—The first road-roller introduced into Scotland was that purchased from Messrs. Aveling & Porter by the Edinburgh City Road Trust, in 1870. The amount and cost of the work accomplished by this road-roller was the subject of a paper read at a meeting of the Engineering Section of the Royal Scottish Society of Arts, Edinburgh, by Mr. D. C. Proudfoot, city road surveyor, in 1882.

From these early and successful attempts to construct road-rollers this firm of Rochester engineers commenced to make and perfect the construction of them on an extensive scale, the leading feature being an adaptation of their form of traction-engine with an arrangement of rollers and turn-table, as shown at fig. 116.

The form and construction of the road-rollers made by Aveling & Porter have been gradually perfected from time to time by introducing important improvements and utilizing the knowledge gained from experience, producing an engine which can be easily managed, and which is economical in working.

254. The latest design of this firm's 15-ton convertible road-roller is shown in fig. 114, with one of Morrison's Scarifiers attached.

Since 1867 this Rochester firm has made and sold over 3000 steam road-rollers, varying in weight from 10 tons up to 25 tons. Most of these are working in this country; but a great number are in use in the Colonies, on the Continent of Europe and in America, while in India alone there are hundreds.

The other principal firms manufacturing road-rollers in this country are Messrs. Fowler & Co., Messrs. Green & Son, and Burrell; while in the United States the most noted are the Springfield, the Pitts, the Harrisburg and the Columbian rollers.

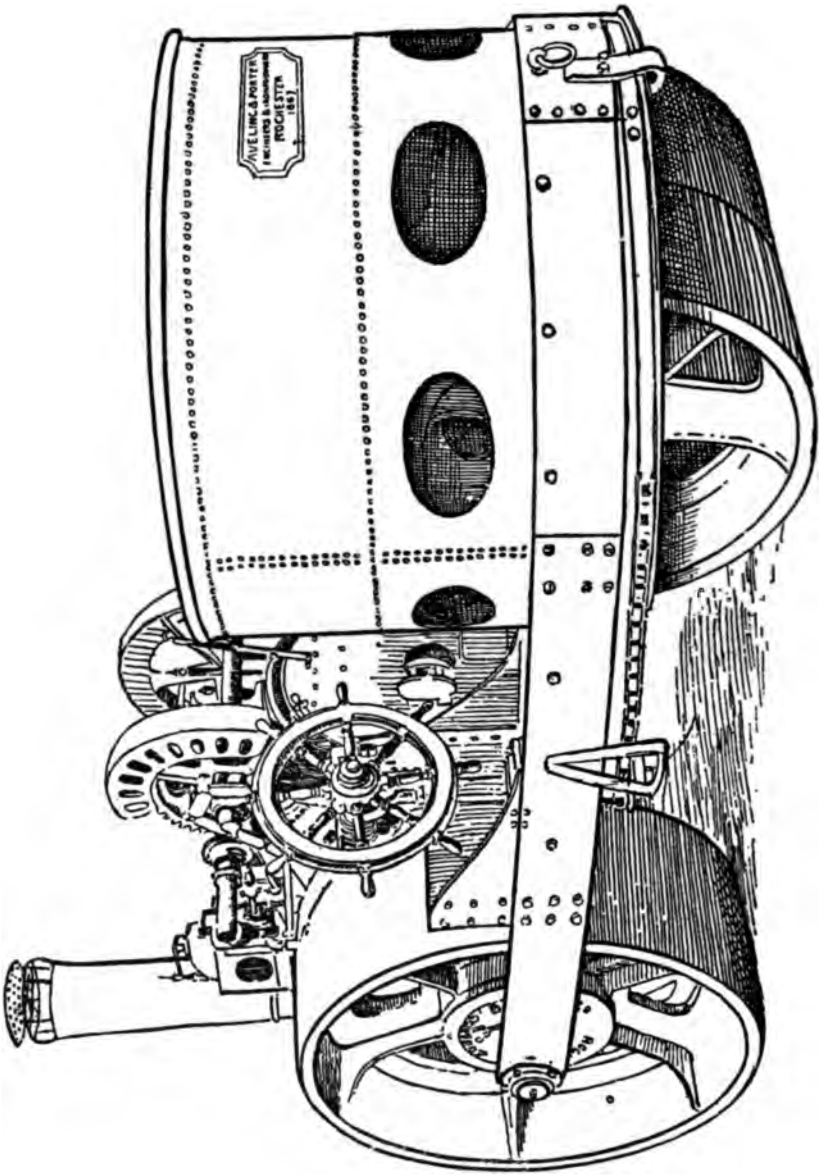

FIG. 115.—Liverpool road-roller.

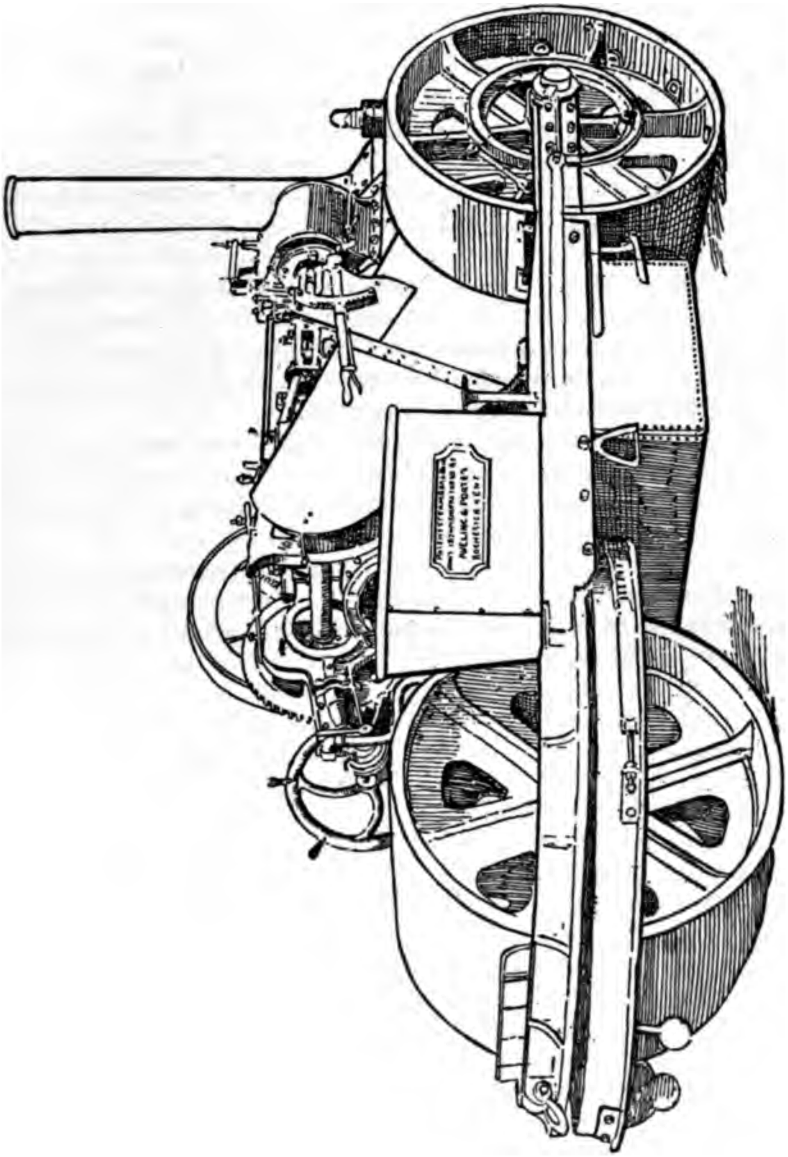

FIG. 116.—Edinburgh road-roller.

255. Advantages of Steam Road-rolling.—The advantages of road-rolling may be summed up as follows:—

(1.) The roads being made for the traffic, a saving of metalling is effected, as the stones are interlocked by the process of consolidation and present only one surface subject to wear, compared with the abrasion inseparable from the system of patching and consolidating by wheel traffic.

(2.) A harder and more regular surface is obtained, the road generally has a better appearance, ease of traction is promoted, injury and suffering to animals are avoided, and the damage to the wheels of vehicles is reduced, owing to the absence of newly-laid or loose metalling lying on the surface of the roads.

(3.) The crust of the road contains only a small amount of binding or soluble matter, consequently there is a material reduction of the quantity of mud in wet and dust in dry weather; and the surface of the roads does not require the constant attention which is necessary with metalling during the long process of consolidation by vehicular traffic.

(4.) Scraping and cleaning are reduced to a minimum by reason of the road being practically impervious to the effects of weather and traffic; the surface wears longer, and the absence of loose stones in dry weather secures greater efficiency and diminished cost of maintenance.

Steam road-rollers are now almost universally adopted on account of the superiority and economy of the work done, the shorter time necessary for repairs or construction, and also the indirect saving effected owing to the reduced wear and tear of horses and vehicles.

256. Different Types of Roller made; Weight and Construction.—Steam road-rollers are made of different weights, chiefly 10, 12, and 15 tons, for use in this country, while a few rollers of 20 and 25 tons have been constructed. The 20-ton roller is used in Paris, while the 25-ton roller is that adopted in Madrid.

The 12-ton engine rolls a width of 6 feet 5 inches, and the 15-ton roller 7 feet 3 inches wide, and these are the class generally used in Great Britain for county work. 10-ton rollers for the most part are employed in the larger towns, owing to the difficulty experienced in connection with gas, water, and other service pipes.

257. A short description of Aveling & Porter's 15-ton roller may be here given. The boiler is of the ordinary locomotive type, the cylinder being placed on the top and at the forward end of the boiler, and surmounted with a steam jacket. The steam is taken direct from the boiler, and admitted to the cylinder without the intervention of steam pipes, thus avoiding loss in the effective pressure of the steam through being condensed.

They are made either with a single cylinder or on the compound principle, and, when necessary, can be constructed so as to convert the roller into a road engine for hauling purposes, by substituting traction wheels for the front and rear rolls. The rear driving-wheels are 6 feet in diameter and 18 inches wide, those in front 4 feet in diameter, set close together, and having a combined width of 4 feet 6 inches. The front rolls are surmounted by a swivelling fork having a vertical spindle working in the fore-carriage bracket, which supports the front end of boiler. Provision is made for the spindle having sufficient play to admit of the front rolls accommodating themselves to the contour of the road. By means of this arrangement on the fore-carriage in conjunction with the worm-wheel and side chains, the steering of the engine is provided for, and operated from the footplate, the working of the engine being under the control of one man. The distance between the centre of the driving-wheels and the front rolls in the 15-ton convertible engine is 12 feet 6 inches, and the weight of the ordinary roller in working order, with scarifier attached, is 16¼ tons, distributed as follows, namely—two-fifths total weight on front rolls, and three-fifths of total weight on the driving or hind wheels, or fully 5 tons on each wheel. This gives the driving-wheels, when the roller is working on a level stretch of road, a compressive force of 4·88 cwts. per inch of width, being twice that exerted by the front rolls. When rolling on a gradient these latter figures will be slightly increased, owing to the effects of gravity and the weight of the water in the boiler being then greater at the rear end of the engine. The brackets for carrying the gearing are formed by the side plates of the fire-box being extended upwards and backwards in one piece, thus obviating the usual unsatisfactory method, common to many road-engines and rollers, of bolting them on to the boiler, which causes a considerable strain and injury, and consequently increases the cost of working and repairing. The wear and tear of the spur-wheels and pinions are reduced to a minimum by being brought close together, and the combination produces the maximum of strength in the working parts. They are fitted with compensatory motion or differential gear, which enables them to be steered round sharp turns easily without slipping. Two speeds are provided, which can be thrown into and out of gear by a single operation by the driver from the foot-plate.

As previously mentioned, the steam road-roller is a special adaptation of the ordinary road locomotive either with single or with compound cylinders. Those constructed on the latter principle, although the first cost is considerably greater and repairs more numerous, are notable for their silent working, the steam first doing duty in the high, and afterwards in the low pressure cylinder. Thus the steam, in passing from the engine, is discharged into the atmosphere at a relatively low pressure, reducing to a minimum the noise from the exhaust when at work, an important matter when rolling in towns or on busy suburban roads.

An engine constructed on this principle can be started readily in any position of the crank, and there is an entire absence of sudden jerks and shocks inseparable from an engine with a single cylinder.

It is also claimed that a considerable saving in the consumption of coal and water required is effected by a road-roller having a compound cylinder over that of one with a single cylinder only, which may result in greater economy of the working expenses, especially when the fuel has to be brought from a considerable distance, and in districts where water is scarce. Another matter of considerable importance is the reduced temperature of the fire-box, owing to the steam being expanded down before passing through the exhaust into the chimney. The fierce draught caused in high pressure or single cylinder engines creates considerable wear and tear to the fire-box and tubes, which does not occur to any great extent in engines constructed on the compound principle.

In selecting a steam road-roller for the consolidation of the metalling in making new or repairing existing roads, it is necessary to consider, in the first instance, the nature or quality of the material which is to be employed for the purpose of construction and repairs. The weight of the roller most suitable in any circumstances will, therefore, have to be in a great measure determined by the quality of the macadam made use of in the particular locality concerned.

The great object to be attained is a resulting coat of metalling compressed to such a degree, without crushing the material, that the interstices are just apparent and contain the least possible amount of binding consistent with the proper cohesion of the stones forming the coating.

To accomplish this effectually with hard and tough road metal the greatest weight of road-roller permissible should be employed which will consolidate the coating without crushing the stones composing it.

258. Experience shows that for consolidating the best materials, described in Chapter IV., the greatest amount and the best work are obtained by the employment of a 15-ton roller, which exerts a compressive force on the material under consolidation of from 4·88 to 5·42 cwts. per inch of width of wheel. For convenience and comparison, the weight per inch of the bearing surface of the different kinds of rollers generally employed is given in Table XXXI.

TABLE XXXI.

Class of Road-roller in Steam.	Weight per inch of width in driving-wheels.
15-ton road-roller, weighing in working order 16¼ tons, driving-wheels 18 inches wide, ...	5·42 cwt. per inch
15-ton road-roller, weighing in working order 16¼ tons, driving-wheels 20 inches wide, ...	4·88 ,, ,,
12-ton road-roller, weighing in working order 13 tons, driving-wheels 17 inches wide, ...	4·59 ,, ,,
10-ton steam-roller, weighing 10¾ tons in working order, driving-wheels 16 inches wide, ...	3·94 ,, ,,

259. On referring to Table VI., p. 38, it will be observed that the greatest compressive effect is produced by carts having wheels with narrow tyres, amounting in the case of No. 14 to 8 cwts. per inch of width.

The increasing number of traction engines and the recent introduction of heavy motor cars will tend to cause much greater wear and tear of macadamized roads than was formerly the case.

It is evident that to obtain the best results, providing the road materials can bear a heavy weight without crushing, the compressive power or effective rolling weight exerted by a 15-ton roller is sufficient for this purpose, and any unit weight beyond 5·42 cwts. per inch of width of tyre will obviously cause displacement of the stones forming the crust of a road. Should these heavy vehicles become general for haulage purposes, and there is no reason why this will not be the case, it is evident that the present method of making macadamized roads will have to be improved, otherwise the cost of maintenance will increase at an enormous rate.

260. Selection of Roller according to nature of Material used, and other Subsidiary Causes.—With macadam, the stones of which are of a less tough variety or of a brittle nature, such as mountain limestone, some granites, the softer descriptions of whinstone, Kentish rag, ironstone slag, and flints, the employment of a roller 15 tons in weight would result in the stones composing a coating of such material being considerably crushed, and probably rendered useless.

It is obviously necessary, therefore, to make use of a lighter roller in such circumstances, the quality of the macadam being a factor in the matter of selection.

The 12-ton roller will be found suitable for the materials mentioned in the preceding paragraph, while in some cases a roller weighing 10 tons may be advantageously used, and in particular cases this is the minimum weight which can be employed successfully. The width which the former covers when rolling is 6 feet 5 inches, while the latter rolls a width of 6¼ feet. It is for this reason that in many of the English counties rollers of different weights are employed, the material obtained locally, and used for macadam, being variable in quality, while the best class macadam for main roads is in many instances brought from adjoining counties where available, and even from centres situated at a considerable distance. The Welsh quarries supply a considerable proportion of the material necessary to the counties lying on the west coast, and many of those inland in an easterly direction, while many of the midland counties are supplied from Clee Hill and the Leicestershire quarries. The 15-ton road-roller already described is used in Scotland on county roads, almost without exception; a limited number of 12-ton rollers are employed in burghs where the matter of choice is determined not so much by the quality of the macadam as by the position and number of the gas and water mains, and also the service pipes, which are, as a rule, near the surface of the road.

The quality of the rock from which macadam is produced being for the most part of a hard, tough, and durable nature, the weight of a 15-ton roller occasions little or no damage to the material when ordinary precautions are exercised.

The amount of work performed in a given time by the different classes of road-rollers mentioned must necessarily vary, and be less in proportion as their weight and width of rolling surface decrease.

261. Quantity of Macadam consolidated by Steam Rollers.—The quantity of material which a road-roller is capable of consolidating in one day will depend on the description of the road-stone and thickness of the coating applied, the amount and nature of the binding used, the available water-supply, and the time lost by compulsory stoppages for the passing traffic.

A 15-ton roller, working nearly continuously, will on moderately level roads thoroughly consolidate a coating of metal 3 to 4 inches in thickness laid direct on the surface of the road under repair, without the intervention of scarifying, and using just sufficient binding to fill the interstices between the stones, from 64 to 70 tons, or about 60 cubic yards each day of nine hours' duration. When working on gradients, however, a less quantity of material can be rolled, diminishing in amount as the incline becomes steeper, owing to the artificial watering necessary for consolidating the coating escaping from the metal, and with it a considerable amount of the binding material, into the water channels and ditches, or down the inclined part of the road past where the operations are being carried on. The amount of work done by a 12- or 10-ton roller under similar conditions and time, allowing for the extra number of passages necessary to be made relatively to ensure thorough consolidation, may be taken at 50 and 40 tons respectively.

These quantities are applicable to cases where from twelve to twenty minutes are lost each hour by compulsory stoppages. When the number and gravity of such interruptions are such that a greater amount of time is consumed, as when working on suburban roads or when rolling in towns the streets of which are not given up to the exclusive use of the engine, the quantity of macadam consolidated each day will be reduced considerably, and in extreme cases the amount may not reach the figures stated by one-half, or 33, 25, and 20 tons respectively.

262. Cost of Steam Road-rolling.—The cost of steam rolling depends on the system adopted, the amount of work accomplished depending on the degree of consolidation requisite and the principle on which the chargeable expenses are calculated.

In many instances the cost is stated by some authorities on the subject at so much per square yard, varying from ½d. to 1d., but as the quantity of road metal which will cover a square yard varies according to the thickness of the material applied, it is advisable, in order to obtain reliable figures, to calculate the cost of rolling at a price per ton or cubic yard consolidated.

The figures in Table XXXII. may be taken as representing the different items which ought to be included in the expenses of steam-rolling continuous coatings of from 3 to 4 inches in thickness, allowance being made when necessary for local differences in the cost of labour and fuel.

TABLE XXXII.

Cost of steam road-rolling.

	Cost per day.
Foreman, 1 man, 4s. 2d.,	£0 4 2
Engineman, 1 man, 4s.,	0 4 0
Sweepers, 6 men, 3s. 6d.,	1 1 0
Man and horse for water-cart, 8s.,	0 8 0
Coals (steam navigation), including carting, 4½ cwts., 12s. per ton,	0 2 9
Oil, waste, and brooms,	0 2 0
Total working expenses,	£2 1 11
Add for repairs and depreciation and insurance on roller, repairs on sleeping-van and water-cart,	0 3 6
Total cost,	£2 5 5

Taking the quantity of metalling which can be consolidated by a 15-ton roller in one day at 64 tons, the cost on the working expenses alone will amount to 7·70d. per ton, and when the amount for repairs and depreciation is included the cost is increased by 0·7d., or an inclusive price of 8·40d. per ton; this is equal to 8·55d. per cubic yard in the former case and 9·33d. in the latter. The working expenses in connection with a 12- or 10-ton roller are almost similar to the expenditure incurred in operating a 15-ton roller; but assuming this to be 36s. per day, and taking the quantity of macadam which these rollers can consolidate as stated at page 240, the cost per ton will be 8d. and 10½d. respectively, exclusive of spreading the macadam. When the road surface is prepared by being picked or scarified, and when the coatings are of less thickness than stated, the cost of rolling will be correspondingly reduced. Should the available source of the water-supply be situated at a considerable distance from where the work is being carried on, it may be necessary to employ an additional water-cart, in which case the cost of rolling will be increased by 1·50d. per ton.

The price per ton, including spreading the macadam, in the district supervised by the author, taking the average of a number of years, has been 9d. per ton for the working expenses, but exclusive of depreciation and repairs. If the latter be included, then the total cost per ton amounts to about 9·63d.

As the cost of rolling macadam per ton may be increased considerably without any corresponding advantage, it is desirable that a sufficient quantity of material should at all times be spread on the road in order to keep the workmen and roller in constant employment. Thus, if the number of men engaged in sweeping the binding be arranged for a daily supply of, say, 70 tons of metal (a usual allowance, but subject to the remarks on p. 240), it will be evident that, should the quantity fall short of this through delays either at the stone-breaker, in the haulage, or generally a short supply, the cost of rolling will be increased accordingly. If the cost is taken as 7½d. per ton for the proper amount applied, then with only, say, 45 tons spread and rolled each day, the cost will be increased to 11d. per ton.

It is evident from a consideration of the foregoing statement that should the supply be much below the quantity of metalling arranged and provided for in each particular instance, the cost of rolling will be enormously increased, and every effort should be made to provide for the maximum amount of work possible, considering the weight of roller employed and the number of men engaged for the purpose.

When the work of rolling is performed by contract, the cost is generally from 1s. 2d. to 1s. 6d. per cubic yard, but this does not include spreading the macadam. The calculations in the foregoing paragraphs are based on the assumption that a suitable and sufficient quantity of binding material can be obtained in close proximity to the work on hand.

263. Binding Material.—The nature of the binding material employed is of vital importance in the durability of a road and the comfort of those travelling. It has unfortunately been the practice in many localities to use any material which could be obtained near at hand, as, for instance, road-scrapings and material of a clayey nature; the results consequently have been unsatisfactory. The effect of using this description of binding material, especially when applied in large quantities, is such that much mud is created in wet, and dust in fine weather; while during alternating frost and thaw, licking up of the road-stones by wheel traffic causes great damage to the road surface. It is quite as essential for comfortable travelling and in a great measure to economical maintenance, that the binding should be relatively of as good quality as the road-stones. No satisfactory results can be obtained by using binding of a greasy nature, even with the best quality of macadam. The amount of rolling accomplished each day is, by using road-scrapings or other promiscuous material, greater, and the cost of consolidation per ton less, than when binding of a reliable nature is employed, but the surface quickly becomes cupped by wheel traffic.

This irregular wear makes a bumpy road, the ultimate durability is decreased, and the renewing of the surface in this manner may prove a failure on economical grounds, while the results are unsatisfactory to all road users.

There can be no doubt, and it is now being more generally recognized, that sand containing oxide of iron, lime, or other cementitious matter as a material for binding in connection with rolling operations, when applied in a limited but sufficient quantity, promotes the durability of a road. The result is a firm, compact metal coating presenting a smooth surface, while the subsequent maintenance is reduced to a minimum.

The difficulty and consequent cost of obtaining this kind of binding material in many districts may preclude its being used. In such cases a material of a light and friable nature, free from vegetation, should be employed, or road-drift and the screenings from the stone-breaking machine may be advantageously employed for this purpose.

When using clean sand great care should be exercised in applying it, as in the event of its being spread over the surface of the macadam before it is 'set,' or sufficiently rolled in a dry state, the sand will be carried to the bottom of the coating by the artificial watering necessary for consolidation, and being irrecoverable, it will form an irregular and undesirable cushion between the old and new metalling. In consolidating macadam of the acid varieties, it is advisable to use loamy sand, in order to ensure cohesion. If clean sand be used in combination with the screenings from the breaking machine a very sound and satisfactory road surface will be obtained.

When renewing the crust of a road with a heavy coat of metalling of from 3 to 4 inches in thickness, the author invariably applies sand when possible, finishing the surface of the road with the screenings from the stone-breaking machine. This gives a smooth, clean surface to begin with, and the metal coating obtained will withstand much more wear than a coating made with an inferior binding. A greater amount of rolling is necessary when sand is employed as a binding material, but economy is promoted, and the results are more satisfactory.

By the application of an immoderate quantity of binding of any description the coating of metal will become unsound or rotten in condition, and if this material be of a clayey nature, will expand during frost, owing to its absorbent properties, and cause the displacement of the metalling in wet weather. The surface will become sticky, which seriously affects the tractive power of horses, while the road itself will suffer by the irregular deterioration of the surface.

The secret of effective rolling is, using screened road-stone of recognized quality, to employ the most suitable binding material possible in quantities sufficient only to grout the interstices of the metal coating, after the stones have been compressed to a degree that further movement in the mass ceases and the material shows just slight signs of abrasion. By this means the least possible quantity of binding is used, but which is just sufficient to ensure cohesion, any surplus being swept off during the later stages of rolling, so as to form a hard surface, and finishing with a coating of fine chips from the stone-breaker.

The amount of rolling necessary to properly consolidate a coating of metal depends on many considerations, but, given a good quality of binding, a sufficient supply of water, and using road-stones of the description particularized in Chapter IV., 3 to 4 inches deep with a 15-ton roller, the requisite solidity will be obtained by subjecting the macadam to 4 ton-miles of engine travel to each ton of material applied. All cupping of the road-stones at the surface of the road will have ceased previous to this stage of consolidation being arrived at, and further rolling will be unnecessary. It is hardly possible to attain this degree of consolidation with a light roller even although it traverses the coating a greater number of times, and in the case of a heavier roller considerable damage is often done to the road-stones before the requisite degree of solidity has been attained.

It will be found, when the surface of a road is scarified and a coating of fresh metalling one stone thick applied, that there is no necessity for employing any additional binding materials, as the old metalling contains a sufficient amount of detritus for the purpose.

If the surface of a road is scarified and the old metalling screened (the method of accomplishing which will be explained in the chapter on 'Road Maintenance'), a sufficient quantity of small stones and fine sand or detritus will be obtained which forms an excellent binding, provided it is not incorporated with any material of a clayey nature or other unsatisfactory matter.

The different items which make up the cost of carrying out the work of consolidating the macadam in this manner is indicated in Table XXXII., page 241. The working expenses need not exceed the amount stated unless the binding has to be purchased and hauled a considerable distance, or there is not available a water-supply affording a sufficient quantity within easy reach of the rolling operations, necessitating extra expenditure in the employment of additional water-carts. These circumstances will determine in a great measure the actual cost of such operations in any particular county or locality.

264. Mileage of Roads which can be undertaken with one Roller.—The mileage of roads which should be apportioned to each roller in a county will depend on the weight of the engine adopted, the rolling width, as also the method by which the work is carried out; either by patching or by spreading the macadam in long stretches the full width of the road. When working, the operations may be considerably affected by the frequency of the interruptions experienced on account of passing traffic and by the climatic conditions. It may be stated, however, that on county roads over which local or purely agricultural traffic passes, one roller will suffice for the work on from 100 to 120 miles of road; but if the traffic is partly due to local industries, one roller is required for from 60 to 80 miles of road. In provincial towns and urban districts 40 to 50 miles would be a sufficient mileage to be properly served by one roller. In manufacturing towns and cities the extent of roads which one roller is capable of being employed on will depend very much on whether the work can be carried out continuously or intermittently only. In the former case a full day's work can be performed, and the quantity of metalling which can be consolidated will vary according to the weight of the roller employed and the other influencing conditions; while in the latter instance possibly only one-half of the amount of macadam capable of being consolidated by the roller under ordinary circumstances may be dealt with in one day.

265. Hiring Road-rollers.—The system of hiring was at one time greatly taken advantage of in England for the purpose of effecting much-needed improvements in the condition of the main roads, immediately after the passing of the Local Government Act, 1888, creating County Councils, but the more economical and satisfactory arrangement of purchasing road-rollers is now gradually being adopted. The hire system, however, is still practised in many counties at the present time even where the mileage of the roads would ensure many road-rollers being fully employed all the year round.

The cause of this preference is somewhat difficult to understand, no valid reason being given for the adoption of hiring, except that it is cheaper to hire and save the annual cost of repairs on the rollers. This has been stated to amount to £30 or £40 per engine per annum in some isolated instances, but (admitting this to be the case) the party who supplies the rollers on hire, or contracts to perform the work at a tonnage rate, must obviously include the cost of such repairs in the charge for performing the work. The cost of annual repairs as stated above is excessive, as will be shown presently, unless some extraordinary expenditure was included in the figures relating to the particular year for which the statistics are given. The cost of hiring rollers varies considerably, but 25s. to 30s. per day may be taken as an average, which sum includes the engineman, coals, oil, and waste.

Taking the quantity consolidated each day at a mean between the rolling capacity of a 15-ton roller and that of a 12-ton roller as 50 tons of metalling, the cost would be 6d.; to this sum must be added the collateral expenses for sweeping and for the use of a water-cart and hire of horse, which amounts to 6d.; this gives an inclusive price of 1s. per ton consolidation, the price per ton increasing as the quantity of macadam rolled becomes less.

The usual contract tonnage price for hiring is 1s. 3d. to 1s. 6d., so that taking the difference between the two systems at the low figure of 4d. per ton or about 30 per cent., and reckoning the useful effect of one road-roller at 8000 tons of macadam per annum, it is obvious that the expenditure incurred for hiring would be sufficient in the course of three or four years to purchase a roller.

The necessity for hiring, however, becomes apparent when the mileage of roads under an authority or urban council is too small to justify them, on economical grounds, in purchasing a road-roller, especially when the quantity of macadam to be consolidated is only sufficient to keep it at work for a few months in each year. In Scotland all the road-rollers are purchased for county work, but hiring to a limited extent is practised in provincial towns and isolated places. These rollers were, for the most part, in use under the old régime of the 'Road Trustees' and previous to the advent of the County Councils, although many road-rollers have been introduced since that date.

In France, when the rolling is done by contract, the amount of consolidation considered necessary is usually stated at so many ton-miles for each cubic yard, the engine travelling at a maximum speed of 2½ miles an hour. This varies according to the weight and width of the rolls, the average being 2½ ton-miles per cubic yard, and the contract price is about 5d. per ton mile, exclusive of the water-supply.

266. **Repairs.**—In the first edition of this book it was stated that the annual cost of repairs could not be then given with any degree of accuracy, as road-rollers had not been in use sufficiently long to arrive at actual figures. It was, however, mentioned what had been necessary up to that time in the way of repairs, and taking into consideration what might be necessary in course of time, the figure of £23 was given as the approximate average annual cost of repairs.

With an experience of nearly twenty years, the necessary particulars can now be given with greater accuracy for the purpose of allowing a sum in the cost of rolling to cover depreciation and repairs.

The following figures are made up from the actual cost incurred; but it must be understood that the rollers have been carefully handled, and any necessary repairs carried out at once.

The cost of repairs in one roller will alone be given, which may form a fair average for others working under similar circumstances, namely, on level stretches and on hilly roads, and practically in steam all the year, except when under repairs or stopped by frost during the winter months.

Up to the fourteenth year the repairs were comparatively trifling, with the exception of a pair of new driving wheels and repairing the fire-box and tubes, etc. These latter, and including sundry repairs, amounted, on an average, to £11 per annum. It was then found necessary to have a new fire-box and general overhaul of all the working parts. This cost £170, and the engine should, it is anticipated, be capable, with ordinary repairs, to run for a period equal to a life of twenty-five years at least. The renewal of the driving and front wheels, especially the former, is an expensive item, and what was considered at one time impracticable can now be carried out, that is, plating the worn-out rims. This results in a considerable saving, and the wear of the metal forming the rims is considerably less than in the original wheels. It should be stated, however, that the wheels for renewal of rims should not be worn too thin, as, in such cases, the renewal is not so satisfactory. The process is to fit steel plates on the old rims and rivet the two together, and, apart from a few of these becoming loose, which can be remedied by counter-sunk bolts, the arrangement is in every way successful. The grip or 'bite' of these steel-plated wheels is as good as that of the original cast-iron ones, and the wear is much more uniform.

The author's experience of the wear of steel-plated rims, rolling road-stones of a very hard description, is equal to $\frac{1}{50}$ of an inch for every 1000 tons of macadam consolidated. The cost of renewing the driving wheels by this method is about £40, and although this is only £10 less than the cost of a complete set of new wheels, experience shows that the life of these renewed with steel plates is nearly doubled. This alone is a considerable saving among the many collateral expenses, especially where a large number of rollers are employed. The total approximate cost of these renewals, including those mentioned, and an annual allowance up to twenty-five years, works out at £21 for each year. The combined cost of repairs and depreciation, therefore, represents a charge of 8 per cent. on the first cost of a roller, or otherwise 3s. 4d. per working day.

267. Judging by the number of steam road-rollers at present in use, an idea may be formed of the high appreciation of road-rolling when it is stated that the firm of Aveling & Porter alone have made and sold 3500 steam road-rollers, of which 2145 are in use in the British Isles; the majority weighing from 10 to 15 tons. In London alone more than one hundred rollers are in daily use on an area of 400,000,000 square yards of macadamized roads, which represent over 2000 miles of road having an average width of 30 feet.

Oil Road-rollers.—A new form of road-roller has been lately introduced which possesses, it is stated, many advantages; Messrs Allen, Dublin, are the makers of this machine. It is essentially an oil engine, and many points of superior construction and economy of working as well as efficiency are claimed for it in comparison with steam rollers. Many of the points claimed, however, do not appeal to experienced road engineers, and it will be interesting to watch the performances of these road-rollers in actual practice, and especially with regard to oil consumption and general repairs.

The cost of steam road-rollers and accessories are detailed in the subjoined table, which applies only to the usual type of machine used; special requirements to suit particular circumstances involve a greater cost.

TABLE XXXIII.

Description of Plant.	Cost of Roller and Accessories.		
	£	s.	d.
15-ton road-roller, single cylinder,	460	0	0
15-ton road-roller, single cylinder, convertible, with roller wheels only, no traction-wheels or fore-carriage,	600	0	0
Set of four traction-wheels and fore-carriage,	75	0	0
12-ton road-roller, single cylinder,	400	0	0
12-ton road-roller, single cylinder, convertible, with roller wheels only, no traction-wheels or fore-carriage,	525	0	0
Set of four traction-wheels and fore-carriage,	65	0	0
10-ton road-roller, single cylinder,	375	0	0
If made compound, extra, 15-ton roller,	75	0	0
„ 12 „	55	0	0
„ 10 „	55	0	0
„ 15 tons convertible,	80	0	0
„ 12 „	60	0	0
Sleeping van to accommodate four men,	75	0	0
Traction wagon, capacity 4 tons,	65	0	0
„ „ 6 „	75	0	0
„ „ 8 „	85	0	0
Water-cart, „ 240 gallons,	35	0	0
Scarifier attached to any class of roller,	100	0	0

Scarifying Macadam Roads.

268. Scarifiers or Machines for Breaking up Macadam Roads.—In repairing the surface of a road by the aid of a road-roller, the usual practice is to lay a sufficient thickness of metalling to bring the contour of the road into proper form, which often involves the application of considerable quantities of material. Laying macadam one stone thick on a hard road and then rolling it, is not to be recommended, both on economical grounds and because great damage often results from the metalling being crushed when so spread. If the surface of a road is loosened to a sufficient depth preparatory to re-forming and applying the macadam, one stone thick may suffice to meet the requirements of the case, which, without this being done, would require a coating of metal of unnecessary thickness being applied to ensure satisfactory results.

It seems strange that, even before steam rollers were introduced, a contrivance for scarifying roads on the agricultural harrow and plough principle was patented in 1817 by Clay, and designated "a harrow which is intended to scarify the uneven part of any road."

It is stated that attempts have been made from time to time, not only in this country but also in France, to construct a machine having the same object as Clay's, and drawn by horses, but it is evident that little or no advance was made in the construction of a practical machine for this purpose until within comparatively recent years.

269. The propriety of scarifying macadam roads does not appear to be fully appreciated, owing probably to a want of experience in the matter, or possibly to its having been so rarely resorted to that the actual work performed by the machine has not been sufficiently known.

In districts where macadam scarifiers have been introduced and practically applied, it is considered to be an indispensable adjunct in connection with steam rolling. This is a subject of considerable importance in connection with the maintenance of roads, and as such operations can be executed by machinery at a considerably less cost than by hand labour, a full description will be given of mechanical scarifiers and of the results obtainable by their use.

270. **Qualifications which a Macadam Scarifier should possess.**—A macadam road-scarifier, to be of any practical advantage, must be of a light but strong construction, easily manipulated, and form part of, or be permanently attached to, the road-roller or traction engine.

It should be capable of being used both when the engine is moving forward and when it is moving backward, while the engine wheels should not be allowed to compress the portion of road just broken up when making a fresh 'cut' parallel with it.

The teeth or tines should be spaced sufficiently close to ensure the crust of the road being completely loosened, and the mechanism regulating the depth of the cut should be so arranged that the teeth or tines can be instantly raised clear of the road when necessary. This is particularly desirable when working in towns in order that crossings, gratings, tobies, or other obstructions may be safely passed while the engine is in motion; the depth to which it is intended to penetrate the macadam will depend on circumstances, but for all practical purposes it need not exceed 4 inches. The working of the machine should be so arranged as to avoid the stones composing the crust of the road being violently strewn about, with the possible risk of incurring danger to pedestrians and vehicular traffic, or damage to house or shop windows when working in populous places. The best-known scarifying machines made within the last few years in this country, and employed in some instances with marked success, are given in the following list in chronological order.

271. **Different Makers of Scarifiers.**—Rutty's road-scarifier, 1884; Voysey & Hosack's apparatus for breaking up streets, etc., 1890; Jackson's road-scarifier, 1891; Wallis's machine for breaking, etc., the surface of roads, 1891; Henderson's macadam road-breaker, 1891; Messrs. J. Fowler & Co.'s road-scarifier, 1894; Morrison's (Aveling & Porter) road-scarifier, 1895; Rutty's road-scarifier, 1896; Burrell & Rutty's road-breaking machine, 1897; Fowler's scarifier, 1897; Marshall's scarifier, 1898; Bomford's scarifiers, 1898; Hosack's scarifier, 1898.

Of the various machines mentioned, the author will describe the main features of Rutty's original scarifier as improved in 1890, and give the amount and cost of work effected by its use. This machine has done excellent work for many years past, and still maintains its position as a capable and effective mechanical appliance under certain conditions. These conditions will be referred to later on.

Morrison's machine, which is manufactured by Messrs. Aveling & Porter, and fixed to their road-rollers or traction engines, will also be described, and details given as to its working capacity and cost.

This machine is capable of performing heavy or continuous scarifying, and of working with equal facility and advantage backwards or forwards. As it is usually attached to the engine, but can be detached in a few minutes if necessary, it is available for work at a moment's notice; this is a convenient arrangement when the repairs on the roads are carried out on the patching system.

The other machines mentioned in the preceding list, so far as any special features possessed by them are of interest, will be briefly noticed in their chronological order.

272. Rutty's Scarifier.—The general features of this machine are shown in fig. 117. It is made up of a heavy cast-iron box or trolley *a*, to either end of which a bracket *b* is fixed, carrying the boss *c* through which the quick-threaded screw *d* in the depth-regulating frame *e* works. This frame is rigidly held in position by deep recesses on each side, between which the boss slides, the lower ends being carried by small road wheels which travel in a line with the axis of the machine, while the means of regulating the depth is provided at the upper end of the frame *e* by a handle *g*. The regulating-frame and bearing-wheel *f* are placed in a

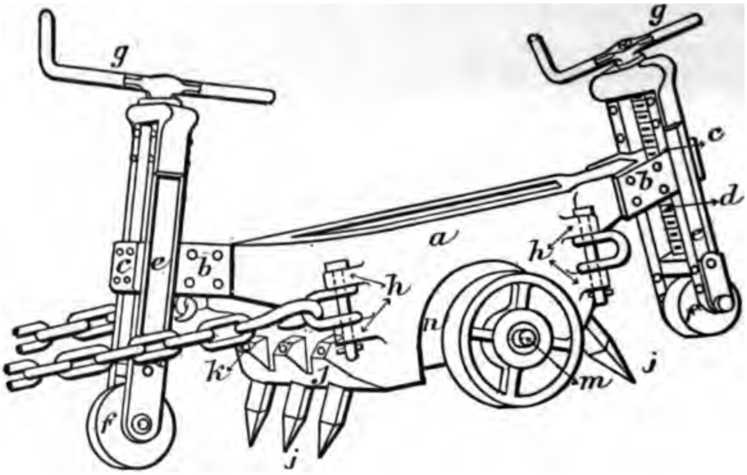

FIG. 117.

raking position, as shown in the illustration, fig. 117. Lugs, *h*, are cast on the box-frame at the corners, to which are attached draw-links and pins, forming the means for attaching the drag-chains. The teeth or scarifying tools *i* are placed in sockets *j*, and pass through the lower part of the cast-iron frame *a*. They are generally set at an angle of 60° with the road, and are held firmly in position by means of screws *k*. The road wheels for supporting the box-frame *a* are carried by an axle *m*, which can be adjusted transversely, so as to permit of the wheel being placed in the recess *n*, by which means the machine can be worked close up to the kerb-stones or edge of footpaths when necessary. This scarifying machine is capable of penetrating hard macadam to a depth varying from 1½ inch to 5 inches. The work is commenced at the crown of the road, and gradually continued towards the side; when the other portion is commenced the engine hauling the scarifier is turned round or reversed if necessary. The width of the cut or extent of surface loosened each turn is about 18 inches. This machine being on the trailing principle, cannot be pushed backwards; the engine, therefore, has to be disconnected from the scarifier when the length of road operated on has been traversed. To avoid the necessity of turning the engine completely round, a draw-gear arrangement is fixed on the front of the engine, by which the scarifier is drawn when making the return cut. It will be obvious that even with this arrangement a considerable loss of time is involved when operating on a short length of road. The time occupied in changing the position of the engine will depend greatly on the aptitude of the driver, but generally it may be taken at 25 per cent. of the actual working time engaged on a piece of road of about three hundred yards in length. The latest arrangement in connection with working this scarifier is to harness it to an engine in front of the driving wheel and alongside of the steering wheels. It is held in position, as far as it possibly can be so under the circumstances, by means of chains attached to the side of the fork, the spindle for carrying the hind wheel scrapers, and a bar of iron fixed at rear of the tender. By this means the scarifier can he hauled in either direction without reversing or turning the engine. The great width occupied by this combination is, however, rather a serious matter on narrow roads. This machine, which weighs 2 tons, performs its work very effectively, and there is little ridging of the macadam when the teeth are working at an average depth; the latest make of this machine has four tines, which are capable of loosening a width of 21 inches; the cost of this scarifier is £100 delivered.

273. Voysey & Hosack's Scarifier.—This machine consists of a double cast-iron frame, the inner or tool frame working within the external one. The front part of the external frame is attached to the tender of the engine by means of a pivot shaft, while at the rear or hind part it is carried by small road wheels.

The road surface is scarified by means of an arrangement consisting of a revolving barrel, in the periphery of which are sockets for holding the tools or teeth, which teeth are inserted and secured rigidly in position by screwing the discs forming the tool barrel tightly together by means of a through bolt and nut.

The rotary motion is obtained by a series of endless pitch chains extending from a chain wheel attached to the counter-shaft outside the fly-wheel of the engine to the shaft wheel at the front end of machine, which operates the axle carrying the tool barrel and fixed between the cast-iron frame. The tool-barrel frame can be made to traverse the external frame so as to enable the machine to work close to the side of the channels.

The depth to which it is intended to lift or scarify the macadam is regulated by means of a screw and handle. The barrel containing the teeth or tools revolves in a direction contrary to that in which the wheels of the engine travel. This machine can be worked in either direction without uncoupling the scarifier from the engine, the motion of which is alternately a pull and a push. The teeth in the tool barrel are arranged in spiral lines around it, the number inserted depending on the hauling capacity of the engine to which the machine is attached and the hardness of the road surface which is being scarified.

The machine is well balanced, and throws but little weight on the engine operating it. It can scarify at the rate of 300 square yards per hour, even when the passing traffic causes considerable delay. The action of the scarifying teeth or tools is such that stones are occasionally strewn about.

274. Jackson's Scarifier.—This machine weighs 3½ tons, and is somewhat similar in appearance and construction to Rutty's scarifier, the principal difference being that the road wheels at either end act as steering-wheels also, instead of being used in connection with the depth-regulating arrangement. Experience, however, shows that such an arrangement, so far as the steering is concerned, is not a necessity in this class of road-repairing machinery.

A lever on the top of the machine enables the scarifying teeth to be quickly lifted clear of the road surface when manhole covers or other such fixtures are met with. The scarifier can break up 300 square yards of macadam road in an hour, when the surface has been previously well watered. The cost of working this scarifier, including hire of engine, repairs to machine and tools, is stated to be $\frac{7}{16}$ of a penny per square yard.

275. Wallis's Road-pecking Machine.—This scarifier in its improved form is attached to the rear end of the tender of a road-roller by means of brackets and spindle or hinge, which admits of a rise-and-fall movement being given to the machine, and a certain amount of lateral play is provided in the arrangement of the drawbar. The machine proper is carried by two road wheels. The pecks, three in number, act when at work in a similar manner to the cutting tool of a rock drill. These pecks are operated by a three-throw crank worked by a three-cylindered engine, the motive power being supplied from the road-roller boiler by means of steam pipes and flexible tubing. In addition to the three-throw crank the machine is provided with a fly-wheel, stop-valve, and governor to regulate the speed of the machine when working. The raising or lowering of the machine is accomplished by means of rack-and-pinion gearing, the regulating of the depth of cut being quickly manipulated by a handle attached to a pinion, which can be locked by means of a lever. The action of the pecks causes the stones to be violently thrown about, so that to avoid damage arising from this cause it is necessary to enclose the lower part of the machine.

It is stated that this scarifying machine can loosen between 300 and 400 square yards of macadam in an hour, the condition of the surface of the road, wet or dry, making no difference in the amount of work done.*

276. Henderson's Machine for Breaking up Macadam.—This form of scarifying machine, the invention of a practical road engineer, consists of a strongly-built iron frame triangular in plan. Two road wheels at the rear end and one at the front end of the apex carry the framework, which has an arrangement fixed in front for attaching it to a special drawbar on the tender of the road-roller. The perforating teeth or drills, nine in number, have a rotary motion; for this purpose each chuck-end or socket of the tool holder is fitted with a bevel wheel carried in proper bearings in a cross girder. These bevel wheels actuate a similar number of bevel wheels or mitre gears keyed on to a horizontal shaft revolving in suitable bearings fixed at each side of frame. The shaft is driven by toothed wheels, and a pulley on the shaft of the upper one connects with and receives motion through the driving-belt working on the fly-wheel of the road-roller; the mechanism can also be driven by shafting.

The depth to which the drills work is regulated by two men by means of side screws, which can be adjusted so as to suit the contour of the road at the haunches or channels. This machine weighs 2½ tons, and nine drills are in operation when the scarifier or road-breaker is working at its full capacity, covering a width of 6 feet. The number of drills, generally three or four, made use of at one time, however, depends on the power of the engine employed to operate the machine and the hardness of the surface of the road, while the work is greatly facilitated by thoroughly watering the macadam previous to commencing scarifying operations.

This machine can only work in one direction; the road-roller, however, need not be uncoupled, as the engine simply pushes the scarifier backwards into the position for commencing another cut. It is stated that, when all the drills are in operation, it can break up a mile of ordinary road composed of flint macadam in one day or an average of 600 square yards per hour when an engine sufficiently powerful is employed, the cost working out at about ⅛d. per square yard. A 10-ton roller is not sufficiently powerful to work this machine when all the drills are made use of, so that it is usual to employ four drills in granite and six drills in flint macadam roads.

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* Paper on "Machinery as adapted to the Breaking up of Macadam," read at a meeting of the Incorporated Association of Municipal and County Engineers at Reading by A. G. Collins, M.Inst.C.E.

277. Fowler's Machine (Evershed's Patent).—This machine is on the principle adopted in land cultivation by steam. The frame is mounted on road wheels, and has depth-regulating and stearing gear; the cutting tools are triangular in shape, and are retained in the sockets by locking screws. The number of teeth may be varied according to the condition of the road, the width scarified at one operation being 3 feet when the full complement of teeth are used. The wire rope, one end of which is attached to the engine, passes round a horizontal pulley of large diameter placed on the top of the machine, the other end being attached to a claw anchor fixed at the side of the road. A length of 40 lineal yards can be scarified at one time; then it is compulsory to stop the work and refix the anchor before commencing another stretch of similar length.

278. Morrison's Scarifier.—This machine is manufactured by Messrs. Aveling & Porter, Rochester, and is fitted to their road-rollers and traction engines. The principal features of this scarifier are handiness, utility, and economy in the working expenses. The different parts of this machine are shown in figs. 118 and 119, the former illustration being a side elevation of the scarifier, attached by plates to the rear or tender end of a road-roller, and placed immediately behind the off-side driving wheel.

The fixed frame *a*, containing the mechanism, is made up of channel irons, angle irons, and plates riveted together; it measures 33 inches by 28 inches by 12 inches, and is fixed to the rear of the tender by means of two steel plates, *b* and *c*, which latter extends to and is embraced by the horn plate close to the firebox, the lower end being stayed to the cross-bar at the rear end of the tender as shown. The outside part is braced by means of a heavy channel-iron connecting piece *d*, which is bolted to the lower end of the fixed frame *a*, and connected to the main axle of the driving wheel by means of a cap bolted on to the boss of the nave *e*; it is further secured in position by an angle-iron brace *f*, bolted to the connecting bar *d* and the top of the frame *a*. This constitutes the shell, or frame, in which the mechanism of the scarifier proper works, and it is evident that the whole apparatus is securely held in position by the arrangement described.

The inner framework comprises the steel rocking block *g*, working on a shaft which carries the double set of scarifying tools, or tines, *h*, secured in sockets by wedge keys. A set of tines, three in number, is placed on each side of the rocking block or 'tool box,' so that they are alternately brought into action when going backward or forward.

The tool-holder is rocked over by a lever *i*, working in a curved slotted bar *j* fixed to the inside frame, and locked in position by means of a screw *k*. A saddle or stop block *l*, at the lower end of the inside frame *a*, admits of the tool-block being firmly held in position either when the rocking lever is locked while scarifying in a forward direction or when the change of motion is reversed. It will be seen that while the lever is in its proper position for scarifying, the rocking block fits closely on the saddle, securing it in a rigid manner, and also retaining the tools or tines at the proper angle when in operation. The through or stop-block bolt *m* prevents the saddle

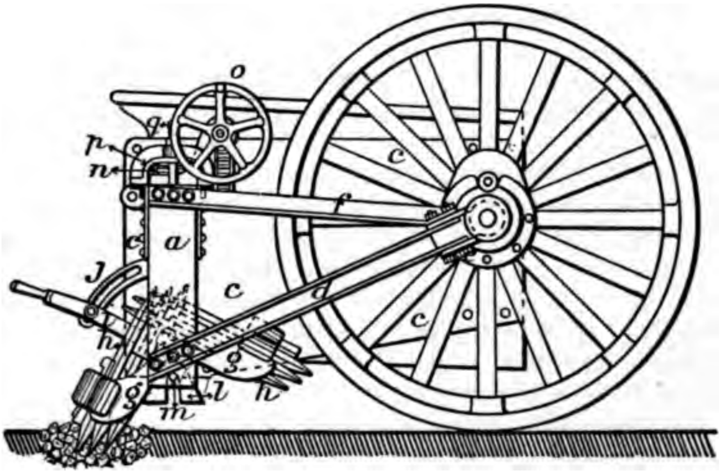

FIG. 118.—Morrison's scarifier, side elevation.

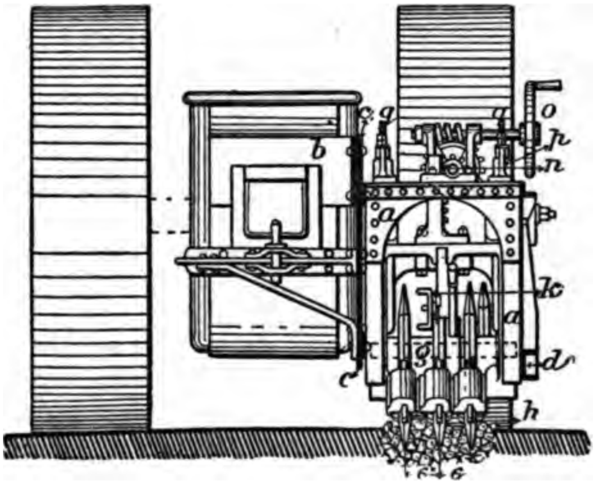

FIG. 119.—Morrison's scarifier, end elevation.

being lowered too far, and at the same time acts as a distance piece, keeping the shell or outer frame in its proper position. The means for raising or lowering the rocking block or tool-holder is provided for at the top of the frame, and consists of a rack and pinion *n*, operated through a quick-acting worm-wheel and worm, which is controlled by the depth-regulating hand-wheel *o*.

A cast steel bridge, *p*, is fixed on either side on the top of the frame through which tension rods *q* pass, secured at the top by nuts, and placed in a vertical recess in the inside frame reaching to the rocking-block shaft. Around these bolts is a strong spiral spring which minimizes, when working, any sudden shocks or vibration that may be transmitted to the engine.

The inner frame, made of cast steel, and comprising the saddle rocking block, lever, and rack arrangement, is held in position by the channel irons at each side forming the outer frame, and which also act as guides when the scarifier proper is being raised or lowered during the progress of the work. This machine works in either direction by an alternate pull-and-push movement, and its merits may be briefly stated as follows.

Being permanently attached to the road-roller in a convenient manner it is always available for use, and can be utilized in executing small repairs, or patching, as well as for continuous work. It can be operated equally well in either direction, and may be run close up to the side of channels, kerbs, or sod borders without the roller wheels passing over them. It is simple in construction, there being no complicated gearing to get out of order. It is a very effective machine, and performs its work thoroughly, expeditiously, and economically, the weight of the machine being only 11 cwts. The amount of work which can be accomplished by the aid of this machine and the cost of operating it will be given in detail later on in this chapter.

279. Rutty's 1896 scarifier was designed for carrying out light repairs, such as patching the centre of a road, for which purpose it is very well adapted. Being fixed immediately behind the tender of the engine or roller it cannot be brought into operation close to the side channels of a road or carriage-way, consequently it can only be utilized to a limited extent.

280. Burrell & Rutty's Road-breaking Machine.—This patent scarifier is intended to be permanently attached to the driving wheel of a road-roller or traction engine. The design is so arranged that when the scarifying tools are in operation, the engine always exerts a pulling movement, when travelling in either direction (which is a distinctive feature), instead of an alternate pull-and-push motion characteristic of scarifiers of the permanently fixed type. By this arrangement the necessity of the roller wheel passing over the newly scarified surface when working backwards is avoided. The machine consists of a triangular frame, rocking on the main axle of the engine. The rocking of the frame and the regulation of the depth to which the tines penetrate the macadam are controlled by suitable devices,

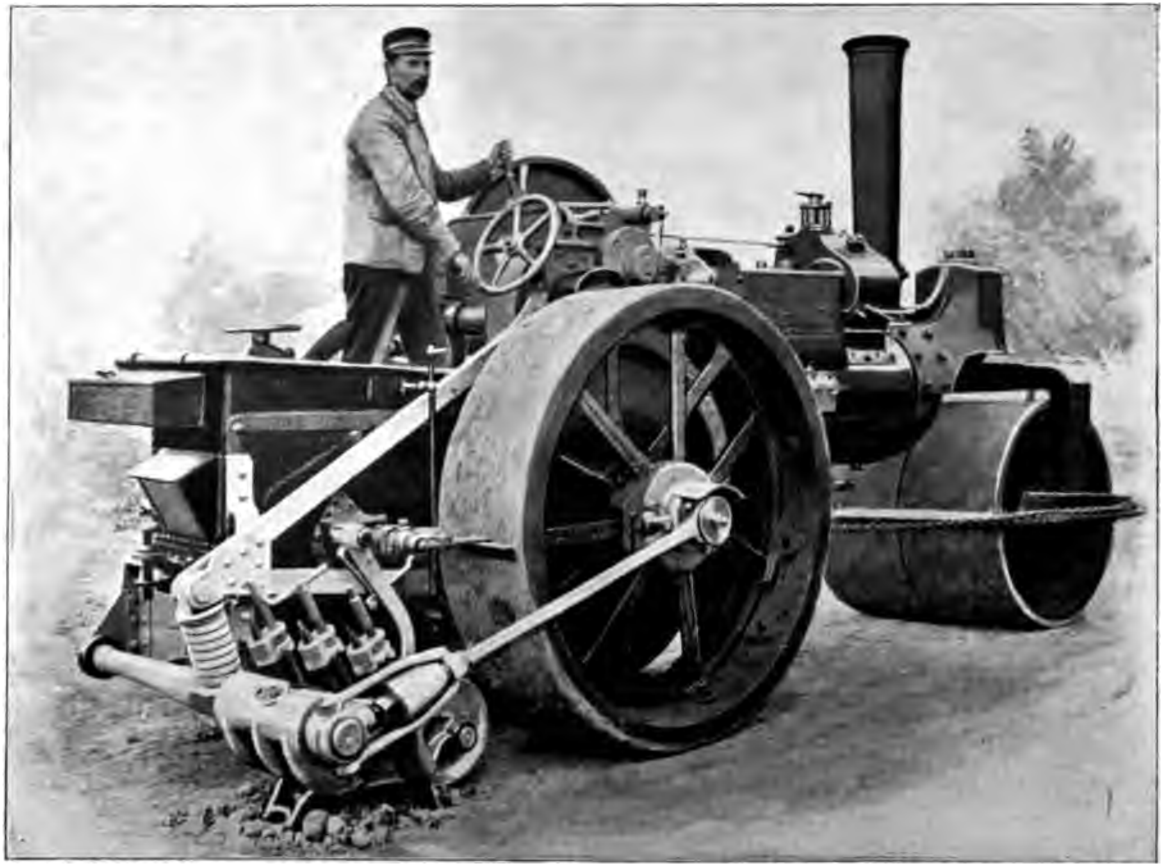

FIG. 120.—Bomford's spring scarifier. [*To face p.* 257.

either by hand, by steam, or by an hydraulic arrangement from the foot-plate.

281. Fowler's (Fowler & Benstead) Scarifier.—This machine consists of a light triangular frame fixed on the main axle of the off-side driving wheel of a roller or traction engine. At the extreme points of the frame the tines or tools are fixed, the depth to which they penetrate being regulated by a screw. There are pivoted extensions at either end of the frame, carrying rollers or wheels which regulate, at either end alternately, the approximate position of the scarifier, and also for carrying auxiliary tines or spikes for loosening the macadam; strong cushioning springs are provided for the screw-regulating arrangement and on the extension pieces, admitting of a slight movement of the small wheels when in a vertical position.

282. Marshall's Scarifier.—This machine consists of a framework fixed at the rear of the engine, and extending the full width of the driving wheels. The guides are fixed on this framework or bed plate, which admit of a saddle-piece or bracket being moved by means of a handle and screw in a horizontal plane or in a transverse direction. The saddle-pieces have spindles or trunnions at their lower end, which carry the swinging-frame containing the tines or tools, and which are capable of being rotated to a certain extent or of being held in position by fixed studs, depending on the direction in which the engine is travelling.

The swinging-frame can be locked in any desired position by means of a bolt working through a slot; the depth to be scarified being regulated by a handle and wheel working a worm and toothed quadrant.

As may be gathered from the foregoing description, the swinging-frame carrying the scarifying tools can be adjusted transversely to any position in the width of the engine.

283. Bomford's Scarifier.—The characteristic feature of this scarifier, which is shown in fig. 120, is the introduction of strong spiral springs to obviate (as is claimed) any damage being done to the engine through vibration. The whole pull, when working the scarifier, is taken by the spring drawbar fixed on the off hind roller axle. There is a small regulating wheel on the main shaft of the scarifier, intended to assist in following the undulations, and to break up the higher parts of a road surface deeper than the hollows. It is constructed on the principle of a fixed or rigid machine, but has not the advantages of such, owing to the springs, which yield considerably when a hard piece of macadam is encountered. The working of the machine is under the entire control of the driver on the foot-plate by means of suitable levers. By such an arrangement it would appear that a considerable amount in working expenses could be saved; but when it is understood that this machine can only work in one direction, the saving gained by only one man working the engine and scarifier is lost on account of the machine having to travel back without doing any work, or by reason of its having to be turned round to make a return cut. The cost of this machine is £70, and it can be fitted to any class of engine. This patented arrangement is now the property of Messrs. Eddison & De Mattos, Dorchester.

284. **Hosack's Scarifier.**—This machine, made by Messrs. Burrell & Sons, is very similar to the scarifier (already mentioned) patented by Rutty & Burrell in 1897. It consists of a heavy triangular frame or bracket pivoted on the driving axle of the off-wheel. The sets of tines or tools are fitted at each end of the frame. The machine can be worked in either direction, the force exerted being always a pull. No matter in which direction the engine travels, it performs the scarifying in such a manner that the surface already lifted is not compressed again by the engine wheels in making a fresh cut immediately adjoining the loosened portion. In this particular Hosack's scarifier is a perfect machine. The depth-regulating arrangements are, however, somewhat complicated, the method of operating this part of the mechanism being as follows:—A lever attached to the end of the rocking-frame in front of the driving wheel of the engine is connected with a toothed quadrant fixed on the boiler barrel, and is operated by a worm and wheel. The leverage is considerable, and liable to impart a large amount of strain on the working parts. A connecting rod with another wheel at the rear end of the engine works the depth-regulating apparatus when the machine is being moved in a forward direction. These regulating wheels are placed so far away from the outside line of the machine that the man operating it cannot properly see the surface of the road which is being scarified.

This does not materially affect the actual depth penetrated by the tines, as the driving wheel, owing to the position occupied by the teeth following close to them, acts in a measure as a guide. In working, however, where numerous manhole covers, tobies, and such obstructions exist, the difficulties in operating it are greatly increased.

This machine weighs about 50 cwts., which is rather a heavy additional weight on one side of the roller when consolidating metalling; for an 18-inch wheel it is equal to about 2¾ cwts. per inch of width of rolling surface. The cost of this machine is £115, and it is illustrated in fig. 121, where it is shown attached to a road-roller.

285. A considerable amount of crushing of the road-stone takes place when the engine on its return makes a cut parallel with that already accomplished. This is caused by the stones being raised and spread by the inner tine over the edge of the hard portion of the road, especially when penetrating to a depth of 3 to 4 inches. This crushing is obviated by three or four men following the machine and raking the material, deposited on the solid road, over on to the loosened portion. A much more effective, and at the same time more economical method, is to attach a trailing plate of heavy iron fixed at an angle so as to remove any stones deposited on the

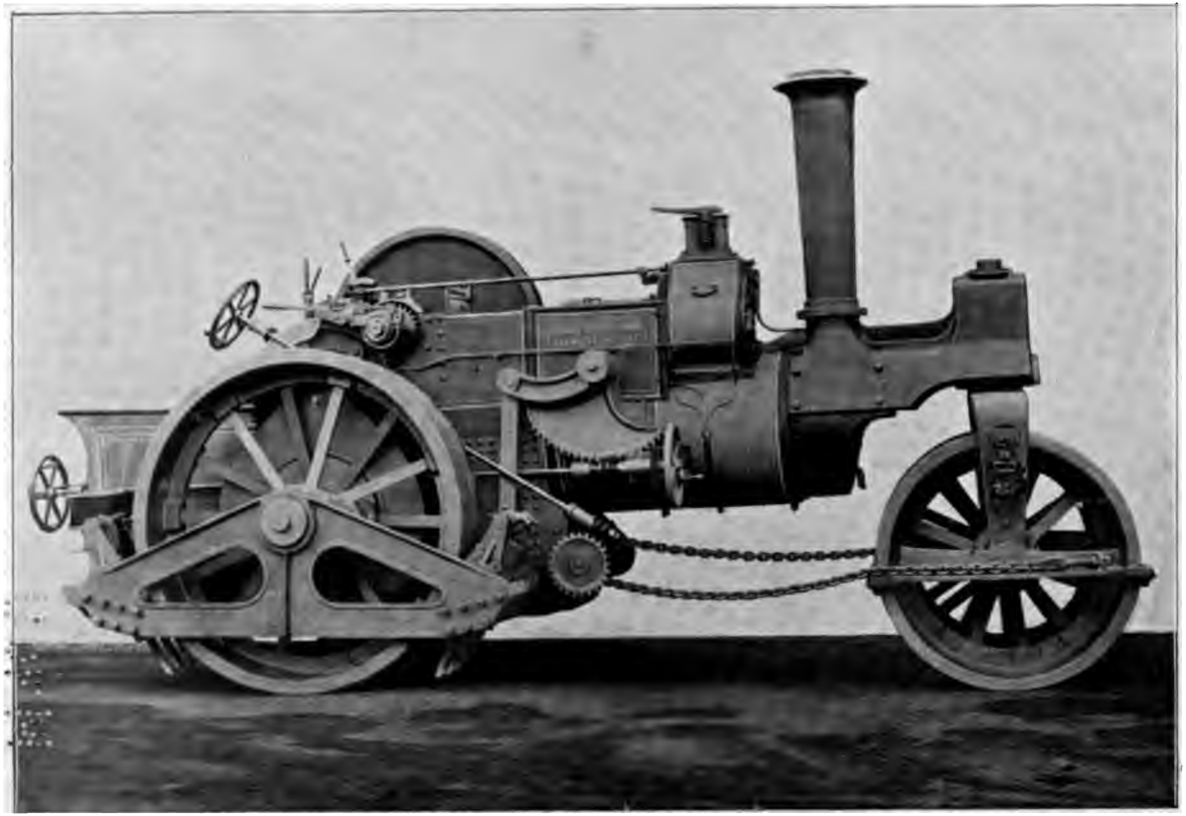

FIG. 121.—Hosack's scarifying machine attached to one of Burrell's road-rollers. [*To face p.* 258.

unbroken portion of the road, clear of the position of the wheel when making the next cut.

286. Hitherto road-rollers were supplied with spikes, which could be fitted into the rim of the driving wheels, for the purpose of loosening the macadam. These, however, cause considerable vibration and strain on the engine, without being efficient for the purpose intended. In America the ordinary agricultural plough, with a special arrangement of sockets or shoes, is made use of for scarifying macadam roads, and for breaking up pavements, four to eight horses being employed to operate it. The principal makers of this type of scarifier are the Syracuse Chilled Plough Company, New York.

287. From the foregoing description of the various types of scarifying machines in use, it will be seen that all accomplish a considerable amount of work proportionate to the power of the engine employed, so that the only ground for choosing one in preference to another is its handiness and economy in working.

It is obvious that for working purposes the preference should be given to the machine best adapted to the rollers in actual use, as there would be no saving in procuring a traction or road engine simply to work the scarifier. For repairing or improving county roads, it is evident that the type of machine operated by means of a trailing movement occupies a considerable extent of roadway, and necessitates in some instances the employment of additional hands to work the scarifier and assist in conducting the vehicular traffic past the machine.

Another weak point in connection with detached scarifiers working on county roads is the necessity of removing the apparatus to some convenient point, entirely clear of the roadway, when the operations for the time being are finished, unless the road is a very wide and quiet one. This constant removal to and fro may constitute a great drawback to their use.

These remarks, however, do not apply to the same extent in the case of suburban and town roads, as refuges in the form of depôts or workshops belonging to the authorities are generally near at hand. Of course these adverse conditions to the employment of trailing scarifiers are entirely removed when the road is given over exclusively to the operations on hand.

The question is—Which machine will perform the work most efficiently and economically, or what is the class of engine available consistent with the conditions already stated? A scarifying machine, no matter of what type, which requires the surface of the road to be previously watered so as to successfully operate it, entails an additional cost in the working expenses, which may be considerable if the available source of supply is at a distance.

A scarifying machine should be preferred which neither forms ridges nor violently displaces the stones when working, as considerable inconvenience and possible danger is thereby incurred. The practical benefits resulting from the employment of a macadam scarifying machine are numerous and important, and as an instance the following may be mentioned as occurring frequently in practice. Many badly shaped roads on which there is a considerable amount of serviceable metalling can be broken up by the aid of a scarifier and re-formed at a trifling cost, which improvement could not possibly be economically undertaken if hand picking had to be adopted. By re-forming the road surface after scarifying, the material may, in many instances, be rolled without any additional metalling being applied.

288. Hand Picking or Manual Labour.—Hand picking or manual labour, besides being an expensive operation, demands the employment of a large number of men to loosen the old surface of the road so as to ensure a sufficient amount of work being prepared to keep a road-roller in constant use. This is not attainable in many districts, recourse being had, under the circumstances, to repairing a road with heavy coatings of metal, when re-facing the surface was perhaps all that was necessary.

289. Cost of Scarifying by Hand Labour.—The cost of scarifying or picking by manual labour varies considerably, and depends on the nature of the macadam operated on, and its condition at the time.

Soaking the crust of the road with water adds considerably to the ease with which it can be picked. The greasy and sodden state of the detritus resulting from this, however, entails a considerable amount of after-labour; and if the old material is to be screened, the process of watering is decidedly objectionable, as it retards rather than aids the operations as a whole.

Under the most favourable circumstances, that is, when the metalling of the surface of a road contains a large proportion of soft material, the cost, including repairs to tools, etc., may only amount to 1·25d. per square yard, while, if the road surface is composed of very hard and compact material, the cost may reach 2d. or 2·25d. per square yard. This is at the rate of about 33 square yards per day in the former case, and 20 square yards in the latter for each man.

In attempting to scarify a road which has been steam-rolled by manual labour, the increased cost for re-sharpening and repairs to the hand picks are relatively high, while the area which a man can accomplish in one day may be reduced to 12 or 15 square yards; under these circumstances the cost of hand picking is from 3d. to 3·5d. per square yard, an amount which would suffice for spreading a coat of metalling on the road one stone thick, when the price delivered on the road is 6s. per ton. Besides being an expensive operation, the danger arising through the stones being projected by hand picking is considerable, and damage is likely to result.

In the author's experience an inclusive price of 1·75d. per square yard for hand picking is an average cost, on macadam composed of hard andesite and basalt, when workmen's wages are at the rate of 4½d. per hour.

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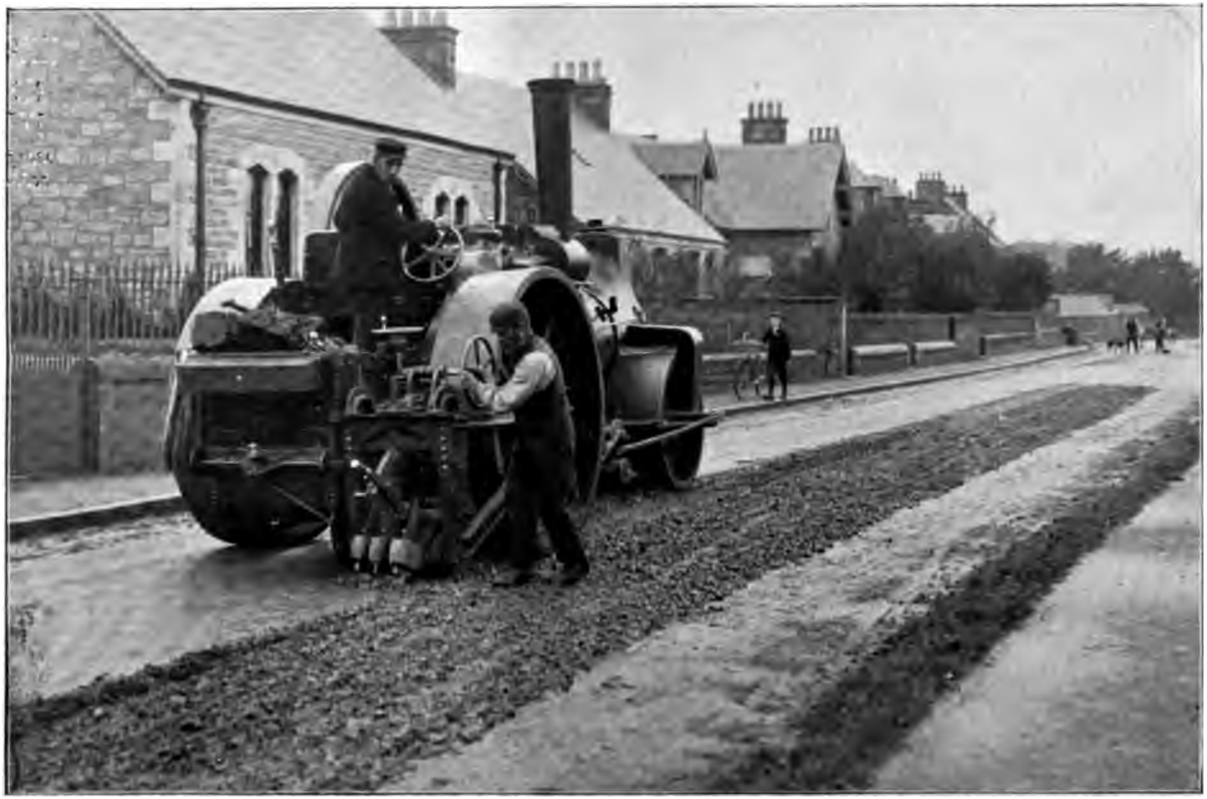

FIG. 122. Recent road-roller (Aveling & Porter's) with scarifier attached. [*To face p.* 261.

290. Amount and Cost of Work accomplished by Rutty's Scarifier.—The amount of work which can be performed by Rutty's improved scarifier depends very much on the hauling power of the engine employed, the nature of the metalling composing the crust of the road, and whether the surface is very hard and dry or in a moist condition. The interruptions from passing traffic also form a considerable item in the actual performance of the machine. It is stated that the machine is capable of thoroughly scarifying 300 square yards of hard macadam, 4 inches deep, in an hour under favourable conditions; but 150 to 200 square yards is considered good work when the exigencies of the traffic preclude continuous working, and an ordinary traction engine or roller is employed.

The cost of scarifying in country districts, under favourable conditions, will, therefore, allowing for hire of engine and wear and tear of the plant and the sharpening of tools, be 0·12d. or one-eighth of a penny per square yard. When the passing traffic is such that considerable delays are experienced, then the cost will be increased to 0·62d., or three-fifths of a penny per square yard. In large towns where the cost of labour, fuel, and the hire of engines are considerably higher than obtains in rural districts, the cost must necessarily be greater, amounting to 0·5d., and in some cases to 1d. per square yard.

291. Amount of Work done by Morrison's Scarifier.—The amount of work which can be performed by one of Morrison's patent scarifiers attached to an Aveling & Porter 15-ton road-roller (fig. 114), will now be detailed, along with the cost of working it, based on the author's experience, extending over a period of ten years, during which time extensive scarifying operations in conjunction with steam road-rolling have been carried out. The scarifier has two sets of three tines or tools, which are used alternately, so that the machine can work in either direction. The tools or tines are made of square bar steel, with tapered points at both ends, as already mentioned, and can be regulated to penetrate and loosen uniformly to a depth of from 2 to 4½ inches, which for most purposes is considered sufficiently deep. The tines or teeth are spaced at 6-inch centres, being sufficiently close to effectively break up the crust of a road, while the loose material is left in a regular manner, causing little or no inconvenience to passing traffic. Scarifying machines which have the teeth wider apart are apt to leave a certain portion of the road surface undisturbed. In consequence of this a series of ridges and furrows is formed, which greatly inconveniences the public traffic and increases the cost of the operation by making it necessary to level the old metalling to a proper contour, while the subsequent rolling is never satisfactory under these circumstances. The width of surface disturbed or loosened by Morrison's machine is 18 inches when the tools are penetrating the macadam to a depth of 4 inches; with a less depth the width of macadam broken up will be correspondingly decreased.

If the road is very narrow it is possible that the width of the roller will not admit of the whole surface being broken up by the machine; it will then be necessary to employ manual labour to complete the operation. Roads having such a narrow width are the exception.

It is the usual practice to commence scarifying at the sides of a road and gradually work towards the centre, when the roller has to be turned completely round in order to proceed with the other half of the macadam surface.

The minimum width of a roadway which a scarifier of this description, attached to a 15-ton roller, can operate on so as to effectively break up the whole of the macadam surface, is 12 feet. A 10-ton roller fitted with one of these machines can easily scarify the whole surface of a road 10 feet in width.

Many circumstances arise which influence the amount of work performed each day, such as the narrowness of roads (as compared with wide ones), steep gradients, and the work having to be carried on during wet weather. The tines or scarifying tools, in each set of six points, when properly dressed and tempered, will scarify on an average 786 square yards, and the cost for sharpening each tine or tool (two points) amounts on an average to 3d. and 3½d. each, or 1½d. to 1¾d. per point. This is at the rate of 0·013d. per square yard of road surface scarified, or $\frac{1}{77}$ of a penny. The following figures detailing the amount of work done and the cost of the operations are based on an average depth scarified of 3 inches on roads the metalling of which extends to a width of from 16 to 20 feet and upwards, either when there is a considerable amount of wheel traffic causing interruptions to the progress of the work, or when the road is given over entirely to the repairs, compared with working on narrow roads under similar conditions.

The extent to which scarifying can be accomplished on a gradient is necessarily reduced considerably as compared with working on a level stretch of road. This is especially the case when the gradient exceeds 1 in 20, as the roller will then be capable of working the scarifier in one direction only, namely, down the incline.

When the surface of a road is damp the work of breaking up the surface is more easily accomplished so long as it is not so greasy as to cause slipping of the roller wheels. When the macadam is soaked with water, or when the operations are carried on during rain, it is advisable to work the machine in a forward direction only. This avoids compressing the already scarified old metalling, by the passage of the wheels of the roller over it when the return cut is made with the engine travelling backwards. When the material is in a comparatively dry state, the driving wheels of the roller passing once over the newly scarified portion of the road does not compress it to such an extent as to prevent its being easily lifted or raked into proper shape.

On level roads of average width, and when the interruptions caused by wheel traffic are not numerous, this machine can break up in an efficient manner the surface of a macadamized road at the rate of 400 square yards per hour. On roads with moderate gradients and under similar conditions of traffic, the quantity of scarifying which can be accomplished in the same time amounts to 350 square yards.

On roads where the gradient exceeds 1 in 20, and up to the limit at which the roller can steam safely tender first, and also on level roads during continuously wet weather, which may necessitate the machine being operated in one direction only, the amount of work done will vary from 250 to 300 square yards per hour.

When the gradient exceeds this limit the area which can be scarified will depend on the facilities which exist for the speedy turning of the roller completely round at the commencement and end of each cut when scarifying one half of the road. Under such circumstances, and when the interruptions are not numerous, the amount of work which can be accomplished in an hour may be taken at from 200 to 250 square yards. These figures apply to roads which had been previously steam-rolled, and are based on the average extent of scarifying performed under the varying conditions mentioned.

Allowing 25 per cent. for hilly roads and for roads having a considerable traffic, the average is 300 square yards per hour.

292. Cost of Working Morrison's Scarifier.—In the following table, XXXIV., the cost of watering the surface is not included in the working expenses, as, for reasons already given, the author does not approve of this method of carrying on the work in the majority of cases. The cost of a day's work of nine hours is made up of the following items:—

TABLE XXXIV.

	Cost per day. *s.*	Cost per day. *d.*
Engineman,	4	0
Scarifier attendant,	3	6
Attendant,	3	0
Coals for engine (steam navigation), including carting, 5 cwts., 12s. per ton, oil and waste 8d.,	3	8
Team work, water-cart for supplying engine; as it is only required occasionally, allow 50 per cent. on a day's hire at 8s.,	4	0
Sharpening scarifier tools,	2	0
Depreciation and repairs on roller and scarifying machine,	3	6
	23	8

When the source of the water-supply is conveniently situated the water-cart is not required, but when it is situated at a considerable distance the exclusive services of a man and horse may be necessary. For 2700 square yards per day this gives a rate of 0·101d., or slightly over $\frac{1}{10}$ of a penny per square yard of surface scarified.

The greatest area which has been loosened by Morrison's scarifier under the author's directions was 650 square yards per hour 3 inches deep, at a cost of $\frac{1}{14}$ part of a penny per square yard, on a road which had been rolled four years previously. This is an exceptional performance, as the work was carried out on a road where few interruptions occurred. The cost of operating this machine in some of the English districts where these machines have been adopted averages about ⅛d. per square yard. This is slightly in excess of the price stated above, but may be accounted for by the higher wages paid, the greater cost of fuel, and the increased collateral expenses. A scarifier attached to an engine on the principle described in the foregoing paragraphs is capable of performing a sufficient amount of work in one hour to keep a road-roller at work for five hours consolidating a new coat of metalling spread over the scarified portion. In other words, from 1½ to 2 hours occupied in scarifying will be sufficient when continuous coatings of metal are applied for one day's rolling.

293. This scarifying machine has, in contrast with the others described, proved the contention that fixed machines are in every way the most serviceable and economical which can be employed. Many of the machines described are only used to a limited extent at the present time, especially those on the trailing principle. The fixed scarifiers, as was expected, are favoured most by road engineers, and it may be mentioned that, in support of these statements, Morrison's machines have been extensively adopted, eight hundred of which are at present in use.

294. Cost of Scarifying by Hand and Machine Compared.—Scarifying by hand labour or stocking, even when average workmen are employed, is far inferior to a modern mechanical macadam scarifier as regards economy in time and cost. On an average one man will pick from 25 to 30 square yards, 2½ inches deep, in a day of nine hours, at a cost of 1½d. to 1¾d. per square yard, which includes the charge for sharpening picks and other repairs. A scarifying machine will do as much work as one hundred men can do in the same time. The saving effected by using a macadam scarifier of an approved form, including all charges, over that performed by manual labour, may, under ordinary circumstances, be estimated at 94 per cent.

CHAPTER VIII.

THE CONSTRUCTION OF NEW AND THE MAINTENANCE OF EXISTING ROADS.

295. In a preceding chapter full details have been given, especially of the methods adopted in selecting the most suitable line in laying out a new road and the manner in which the construction is carried out, embracing the earthworks, drainage, and bridges.

The methods employed in quarrying the material, reducing the rock to road metal, and its subsequent consolidation by steam rolling, have also been described in detail, the cost of each operation being taken from the results of practical experience.

296. The method of constructing a new road, by which is meant the part forming the bottoming and top metalling, and the maintenance of roads generally, as practised at the present time, will now be described. To make and maintain these in an efficient manner requires careful investigation and consideration.

Modern exigencies are such that machinery is employed almost exclusively in the construction and repairing of roads, and has to a considerable extent superseded the principles and methods adopted in road making by the two great pioneers, Telford and Macadam.

In the method followed by Telford, who was called upon to lay out new roads and improve the line and gradients of existing ones in different parts of the country, the type of foundation adopted depended on the local supply of suitable material. Telford's name is associated with the system of hand-set stones as a pavement foundation on which the top metal or wearing surface is placed. In the construction of many new roads, and the alteration of existing ones, where suitable material could not be obtained for a paved foundation, Telford used what could be procured locally, such as gravel or layers of chalk and gravel.

297. Telford's Specification of Roads.—The following specification of a 30-foot pitched foundation roadway was that adopted by Telford, and a similar form is occasionally employed at the present time when making new roads:—

"Upon the level bed prepared for the road materials a bottom course or layer of stones is to be set by hand in form of a close, firm pavement; the stones set in the middle of the road are to be 7 inches in depth; at 9 feet from the centre 5 inches; at 12 feet from the centre 4 inches; and at 15 feet 3 inches.

"They are to be set on their broadest edges lengthwise across the road, and the breadth of the upper part of the said pavement is to be broken off by the hammer, and all the interstices to be filled with stone chips firmly wedged or packed by hand with a light hammer, so that when the whole pavement is finished there shall be a convexity of 4 inches in the breadth of 15 feet from the centre.

"The middle 18 feet of pavement is to be coated with hard stones to a depth of 6 inches. Four of these 6 inches to be first put on and worked in by carriages and horses, care being taken to rake in the ruts until the surface becomes firm and consolidated, after which the remaining 2 inches are to be put on.

"The whole of the stone is to be broken into pieces as nearly cubical as possible, so that the largest piece in its longest dimensions may pass through a ring 2½ inches inside diameter.

"The paved spaces on each side of the 18 middle feet are to be coated with broken stones or well-cleaned stony gravel up to the footpath or other boundary of the road so as to make the whole convexity of the road 6 inches from the centre to the sides of it, and the whole of the materials are to be covered with a binding of 1½ inch of good gravel free from clay or earth." *

A cross-section of Telford's roads as specified above is shown in fig. 122.

It has been already observed that Telford did not always make use of a pitched foundation, but employed such material as gravel, which was applied on parts of the road between London and Shrewsbury, while this class of bottoming was utilized in many of the new roads constructed by him.

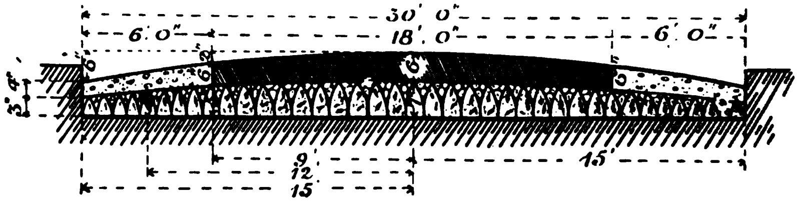

FIG. 122.—Cross-section of a 30-foot road (Telford's).

It was the complete separation of the road metalling from the subsoil that Telford aimed at in adopting a pitched foundation, in order to prevent the useful wearing material coming into contact with the natural soil. He also recommended, when the drainage was difficult to effect, that gravel,

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* *A Treatise on Roads*, by Sir Henry Parnell.

sand, vegetable soil, and chalk should be used, but he generally advised the adoption of the former method when suitable material could be conveniently procured.

298. Macadam's System.—Macadam's system differed materially from that of Telford, but both Macadam and Telford insisted on the necessity of thorough drainage of the formation or bed of the road and subsoil, which had prior to that time been entirely neglected in road making.

Macadam was satisfied with laying the metalling directly on the surface of the ground, after the irregularities had been levelled and side ditches formed; or, in other words, he preferred to build up the road above the surface of the ground.

The method of construction common previous to Macadam's time, and practised in many instances during recent years, was to cut a trench or 'box' sufficiently deep to retain the road material. This arrangement was condemned by Macadam as detrimental to efficient drainage.

He contended that the use of metal broken to a small cubical size, which would unite by their own angles into a compact impervious covering, ranging in thickness from 5 to 9 inches, combined with perfect subsoil drainage, was sufficient for any class of traffic.

To Macadam is due the credit of having been the first to direct public attention to the great necessity of properly breaking the material to a uniform size and cubical form, ranging from 1½ to 2 inches, and weighing less than 6 oz. He was instrumental also in bringing the management of the highways into a regular system under qualified surveyors.

The services of Macadam and his staff of assistants were in great demand over a considerable part of Britain at the beginning of the last century.

299. Advantages and Defects of Macadam's and Telford's Methods of Construction.—Of the two systems much can be said, especially when they are severally applied to the varying conditions and nature of the different soils met with in practice.

A paved foundation, to be of any advantage, requires to be very carefully executed with the best possible class of materials, and even then there may be a large number of unfilled spaces which is inseparable from this method of construction. These act as drains and permit the water to reach and soften the natural soil; the repetition of this process moves the foundation and destroys the cohesion of the wearing part of the road. Defective drainage, even of a temporary nature, will cause this; the subsoil gradually working upwards is mixed with the metalling, while the latter is pressed down into the bottoming of the road. A road formed entirely of broken stones and consolidated by wheel traffic does not present any voids; but as the interstices are composed to a large extent of soft material, more especially at the lower part resting on the subsoil, the crust of the road is liable to suffer if situated on a damp subsoil of a retentive nature.

The bottoming of a road is sometimes carried out in an indiscriminate manner, and the so-called 'pitched pavement' is often made with no better material than that obtained from old buildings in the form of freestone, bricks, and lime rubbish tipped on the formation level of the road in a promiscuous manner, and roughly graded to the required contour.

A form of construction combining in a measure a compromise between the two methods may be adopted with great advantage. A bottoming of stones about one-third of the size adopted for a pitched foundation, and consequently two or three times larger than ordinary macadam, spread to a sufficient thickness, then covered with a coating of ordinary road metal consolidated separately by steam rolling, has been attended with beneficial results. By adopting this method of making roads the cost of construction is reduced compared with the expensive methods inseparable from the respective systems carried out by Telford and Macadam.

300. The great advance in the use of mechanical appliances in road construction and maintenance has made possible what could not hitherto have been accomplished, not only from a practical point of view, but by reason of the greater efficiency and economy attained.

Previous to entering into the details of the construction of roads it will be necessary to consider the nature of the soil or bed on which the proposed road will rest.

The preliminary work of grading and forming the cuttings and embankments was described in a previous chapter which treated of the work necessary to be accomplished in general. The nature of the ground on which the road is to be placed demands attention, however, and apart from the under drainage therein treated, the several kinds of soil composing the strata necessarily require different treatment.

301. The Effects of Subsoils on the Methods of Construction adopted.—In constructing a new road over sand or gravel, which is the simplest case met with in practice, it is quite unnecessary to adopt a pitched foundation. On the other hand, if the road bed is a retentive clay, the spreading of metalling directly on the soil, according to Macadam's principle, would be a failure.

In the first case the natural drainage cannot be improved upon, and consequently an expensive pitched foundation can be dispensed with, while the system advocated by Macadam would be applicable.

On a road bed the soil of which is of a clayey nature, subsoil drainage can only partially relieve the general surface on which the road materials are to be placed. Under these circumstances it would be inadvisable to set a pitched foundation directly on such a surface, as in the event of the subsoil drainage becoming temporarily inoperative, or should the material composing the crust of the road be disintegrated by the alternate action of frost and thaw resulting in the metalling being made permeable, the road bed would become saturated with water in rainy weather. The clay would then gradually rise between the paved foundation stones by reason of the pressure exerted by the wheel traffic pressing the metalling downwards. By such a process considerable injury to the macadam of the road would result, while the incorporation of an undue amount of soft material in the road coating must necessarily, sooner or later, deteriorate and possibly destroy it.

A road constructed on Macadam's principle would likewise suffer, probably to a greater extent, by being placed on a clay bed under similar conditions. In such circumstances it is advisable to apply a suitable material to entirely separate the soil from the road material. This is readily accomplished by spreading a layer of furnace ashes, sand, or other material of a similar nature from 3 to 6 inches thick over the surface. This at once forms a cushion to receive and thoroughly separate the road material from the soil, while at the same time this intermediate layer admits of perfect under drainage. It may be an expensive means of efficiently carrying out the work when suitable material cannot be procured locally, but economical maintenance can only be looked for by adopting approved methods of construction.

Too many roads, unfortunately, have been constructed without such precautions being taken, with results which are not only apparent from the relatively high cost of maintenance, but also from the surface requiring almost constant attention and repairs, while the necessity for scraping and the removing of mud during wet weather is greatly increased.

It is advisable when the road is formed in rock cuttings to spread a layer of sand or other material of a light nature, so as to fill up the irregularities of the surface, and that will also form a cushion for the road materials to rest on. Should the bottoming or road-stones be placed on a hard surface, as in the case of rock, the material is apt to be pounded and destroyed during the process of consolidation.

The practice of thoroughly consolidating the ground when forming new roads by means of a light roller previous to commencing the actual structure, has much to recommend it. This operation should be carried out in dry weather, and any depressions on the surface that may be caused by the passage of the roller should be made good with the same class of material as the surrounding soil. The process of rolling must be repeated until a uniform and solid bed is obtained which will enable the surface of the ground to sustain the superstructure, and the weights brought upon it.

302. Method of Construction adopted at the present time. — A system of bottoming roads combining the methods practised by Telford and Macadam, has long been adopted by engineers and surveyors. It consists in spreading the metalling on a layer of 3- or 4-inch cube stones from 6 to 12 inches thick. The advent of the steam roller has materially aided this form of construction, the practical and economical benefits of which show that such a method may be looked upon as almost perfect for macadamized roads.

The first points to be considered are the gradients and the width of the proposed road, and the amount of contour or convexity necessary to adequately drain its surface.

303. **Width of Roads.**—The width of a new road will be determined by the prospective amount of wheel traffic.

It is a common practice to make a road sufficiently wide to allow of two or more vehicles passing each other easily when travelling fast. For ordinary road traffic 12 feet of metalling will be sufficient, but this may be increased to 20, 25, 30, and 35 feet according to circumstances; but in any case it must be adapted to the probable amount of wheel traffic.

An unnecessarily wide road will cost more in proportion to maintain than one which is of the proper width, while the first cost of construction is, so far, practically thrown away. If a wide road is not kept in good order it assumes a very untidy appearance. A narrow road with heavy traffic is, on the other hand, generally very difficult and expensive to maintain.

In most cases roads are made narrow, because the amount of money available will not suffice for making them wide; but there is no economy in making a road either narrower or wider than is required by the exigencies of the locality. When the requirements necessary to accommodate the traffic of future industries which may arise in a district cannot be determined with any degree of certainty, it is advisable to make provision for it in forming the earthworks. The road proper may be made to suit the existing requirements of the traffic, so that should necessity demand it the roadway can be widened at any future period.

The width of existing roads necessarily varies according to the geographical position which they occupy. An ordinary country road may, in view of its importance, be metalled to a width of from 10 to 15 feet, while a main road may vary from 15 to 25 feet.

Roads situated between large towns, and those in suburban districts, are usually 25 to 30 feet wide, while city roads generally have a width of from 30 to 45 feet. In many instances, however, 50 to 60 feet has been adopted in laying out new streets in the larger cities, while a width of 100 feet and over is proposed for some of the principal thoroughfares in the metropolis to relieve the congestion of vehicular traffic, which has been expanding to an enormous extent for many years past.

The widths stated do not include footpaths, which are usually provided on one side of the road, and in many instances on both sides, as in villages and populous places.

The footpaths generally occupy a width of 6 to 7 feet, so that on county main roads, exclusive of side verges, the total width of roadway may be from 21 to 31 feet, while in the case of suburban roads, with footpaths on either side, the entire width is generally from 37 to 42 feet.

304. Contour of Roads and Minimum Gradients.—The cross-section which should be given to a road of certain width is a matter of great importance. It is usual to construct a road which is practically level longitudinally with more convexity or a greater contour, than one which has a minimum gradient of 1 in 80 to 1 in 100. The latter inclination will, even should the convexity of the road be inconsiderable, enable the surface water to be efficiently drained to the side channels.

The best form of cross-section to give, like many other details in connection with road work, is a matter about which a great diversity of opinion exists.

Macadam considered "that a road should be as flat as possible with regard to allowing the water to run off it at all, because a carriage ought to stand upright in travelling as much as possible."* The rise or versed sine given by Macadam was 3 inches on a width of 18 feet, his view being that, if the surface be well made and smooth, the water would run off freely with such a convexity.

Telford recommended the form to be that of a flat ellipse, the rise being 6 inches on a road 30 feet wide.

Many authorities have advocated a cross-section composed of straight lines falling towards the channels at an inclination of 1 in 24, and joined by a short curve at the crown of the road. By adopting this form of cross-section it is obvious that the contour will soon be destroyed by the inclined flat sides wearing into hollows between the crown of the road and the haunches. When the central portion of a road is worn flat, or there is a want of convexity, the surface rapidly becomes destroyed by the wearing effects of the traffic and defective drainage combined. The practice of giving an excessive contour to roads, or, as it is sometimes termed, making it 'hogbacked' or 'barrelled,' should be avoided, as it is with difficulty that vehicles can travel over them with safety except at the centre. A road having an excessive rise, besides being dangerous, either causes the wheel traffic to be confined to one track at the crown of the road, or when travelling on the sides the tendency of the wheels to slip or travel towards the channels creates a considerable amount of wear on the road surface.

It is evident, under these circumstances, that the labour of horses is greatly increased, while the wear to the wheels of vehicles is aggravated. The excessive contour which a curve at the crown of a road joined by two straight lines produces is shown in fig. 123, which also shows a flat ellipse for a similar width of road.

The best convexity for all practical purposes is a rise of from $\frac{1}{60}$ to $\frac{1}{40}$ of the width of the metalling. The form should be that of a flat elliptical curve, which, besides admitting of the greatest amount of wear to be obtained from the metal coating, is sufficient to pass off the surface water freely.

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* *Parliamentary Report on the Highways of the Kingdom*, 1819, p. 22.

The former rise gives a transverse gradient of 1 in 33 nearly, for three-fourths of the width of the roadway, and this convexity is made use of on suburban roads and those maintained on the patching system. The latter rise, namely, $\frac{1}{40}$ of the width of the metalled portion of the roadway, is that invariably adopted when the metal coating is spread the full width and steam-rolled; it is a gradient nearly equivalent to 1 in 25 for a considerable breadth of the central portion of the road. This additional rise is necessary, because after a few years' wear the general contour approaches that of the former, or 1 in 33, and that before the surface has to be refaced.

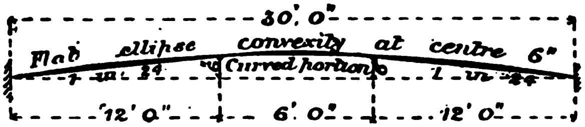

FIG. 123.—Elliptical, and straight line and curve contour.

305. Details of Construction.—When the road bed has been prepared, a layer of stones varying in size from 3- to 4-inch cubes, each weighing from 1¼ to 1½ lbs., is spread over the surface to the intended width, the thickness being regulated according to the class of road and the amount of traffic likely to pass over it. The bottoming material may be prepared in the quarries and subsequently conveyed to the works, or the rough material is carted direct to the road under construction, which is the method generally adopted, and deposited on the formation bed, when it is hand-broken and formed to the required width and thickness. Where the material for bottoming is broken in this manner the cost will be from 6d. to 8d. per ton, which includes spreading, but is exclusive of the cost of quarrying and haulage.

A depth of from 6 to 9 inches for roads in country districts may be considered sufficient, the thickness being increased to 12 inches for suburban and town roads. The formation bed of county roads is generally made level transversely, the requisite contour being attained by increasing the thickness of the bottoming and metalling in the centre of the road. This, of course, presents a road the sides of which are not equal in strength to the central portion, but as from 50 to 75 per cent. of the wheel traffic on this class of roads passes along the middle part, the wear is there greatest and the flanks or bermes are relatively strong in proportion.

For suburban and town roads, or for exceedingly wide county roads, where the wheel traffic spreads entirely over the surface, and is therefore equally distributed upon the road, it is desirable to form the foundation of a uniform thickness and of equal strength. This is accomplished by making the formation bed of the road conform transversely to the contour which the finished surface will assume when finished. Figs. 124 and 125 show a cross-section of a country road and that of a suburban road respectively.

The bottoming, whether for suburban or country roads, should in every case be steam-rolled, the interstices being filled with sand or gravel brushed into the joints during the final stages of consolidation. Artificial watering should not be permitted until the rolling is completed, when the work may be tested by sprinkling water over the surface to ascertain if the voids between the stones forming the bottoming are thoroughly filled. Great care is necessary, however, when applying water under these circumstances, as should an undue amount reach the bed of the road and soften the soil, depressions will be formed by subsequent rolling, which may possibly result in a permanently weak place being formed.

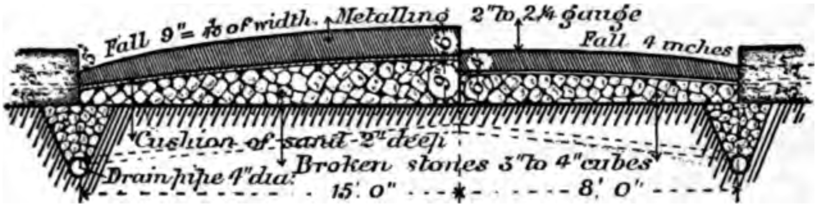

Fig. 124.—Cross section of a country road.

In the event of depressions being formed, resulting from the unequal capacity of the soil for bearing the material composing the bottoming, or by reason of water finding its way to the road bed or formation, it becomes necessary to add more material of the same nature and quality, in small quantities, until the whole surface is brought to a regular and uniform contour.

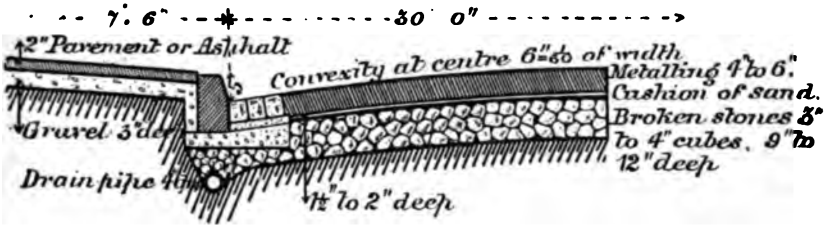

Fig. 125.—Cross-section of a suburban road.

On this foundation or pavement a cushion layer of sharp clean sand or fine gravel should be spread, from 1½ to 2 inches in thickness, to receive the top metalling. If this precaution is not taken, the metal coating, especially if it be of moderate thickness, will be crushed by the action of the roller wheels pressing the stones on the hard consolidated bottoming.

The top metalling may now be proceeded with and spread to a thickness, according to the requirements considered necessary, but generally varying from 3 to 6 inches. If the latter thickness is necessary, it will be advisable to carry out the work by spreading the material in two layers and consolidating the first before applying the second coating.

In either case the rolling should be commenced at the water tables or outside edge of the metalling, and be gradually extended towards the crown of the road. After repeated passages of the roller, and when the macadam has been properly set or interlocked, binding of a sandy description may be applied by shovels, care being taken to spread it evenly over the surface of the metal coating.

The rolling is continued meanwhile with the addition of an artificial supply of water and brushing, until all the interstices between the stones are filled up.

Great care must be exercised to prevent any unnecessary watering, which, besides doing no good to the metalling, might penetrate and do damage to the foundation by softening the natural soil. The surface is finished by applying a coating of screenings from the stone-breaker one-half inch thick, the roller passing backwards and forwards until a thoroughly solid and smooth surface is obtained, any surplus binding being swept off during the final stages of rolling.

306. Cost of Rolling Road Bottoming.—The cost of steam-rolling from 6 to 12 inches of bottoming and filling the voids with sand, assuming the latter has been obtained within a reasonable distance of the work, may be put down at 3d. or 4d. per ton of material consolidated. The consolidation of the top metalling in forming new roads requires a considerably longer time than does that of a coating of metal spread on an existing road. This may, in certain circumstances, amount to 1s. per ton of metalling consolidated, or an average of 8d. for the combined operation of rolling the bottoming and top metal when these quantities are of about equal depth.

307. Maintenance of Macadamized Roads.—To maintain an existing road in good order it is necessary to perform the work either by annual repairs or by applying a wide and continuous coat of metalling and then steam-rolling it. Roads repaired by the latter method, depending on the quantity of metalling applied, may wear for a considerable number of years with but little attention.

Wear on Roads.—The wear of the macadam composing the crust of a road is due to two causes, namely, the traffic and the weather. The amount of the former, and the wearing effect due to wet weather and wheel traffic, determine to a great extent the quantity of material necessary for the efficient maintenance of the surface of a road. Frost has the effect of expanding moisture in the crust of a road in proportion to the amount of soft or muddy material which it contains. Alternating frost and thaw, when the road contains a high proportion of detritus to hard material, break up and in many cases destroy the surface of roads, even when the thickness of metalling is ample to sustain the heaviest vehicular traffic in ordinary circumstances.

Sir J. Macneill estimated the wear due to atmospheric causes at 20 per cent. of the total; while of the 80 per cent. due to traffic, 60 per cent. was caused by the action of the horses' feet, and 20 per cent. was due to the wheels of fast coaches. In the case of heavy or waggon traffic, the wear caused by the feet of horses was stated to be 44½ per cent., and that by the wheels 35½ per cent. Any obstruction on, or irregularity of, a road surface increases the draught considerably, and the wear or injury caused by the action of the horses' feet is augmented accordingly.

It is obvious that on a hard smooth surface the combined wear caused by the action of horses' feet and the wheels of vehicles, especially in the case of heavy loads, is comparatively less than on a road the surface of which is uneven or of a yielding nature.

308. Repairs by Patching.—In patching a road the quantity of metalling which it is necessary to apply each year will, as already pointed out, have to be determined by the amount of wheel traffic passing over it, the quality of the macadam employed, the situation, whether shaded or open, and the facility with which the surface and subsoil drainage can be disposed of.

On practically level roads the consumption of material for repairs, compared with a similar length of road situated on a gradient of 1 in 80 or 1 in 100 and subjected to the same amount of traffic, will require from 15 to 25 per cent. more material to maintain the surface in an equally good condition. The annual wear in thickness of a metal coating may vary from one-third of an inch on light trafficked roads to 3 or 4 inches on roads subjected to heavy and continuous traffic.

It is difficult to measure the annual wear, as the depth generally given is that of the material laid in a loose state and subsequently consolidated by wheel traffic.

The quantity of material necessary for repairs is usually stated at so many cubic yards or tons per mile of road. On roads over which the traffic is light the annual quantity of macadam necessary for repairs may not exceed 20 cubic yards per mile, while for ordinary country main roads the average consumption of material may be taken at 40 to 50 cubic yards per mile, and for roads situated between large towns the annual amount of metalling requisite to keep the surface in good repair may amount to 200 or 400 cubic yards per mile. In the vicinity of large manufacturing towns, however, the quantity may rise to 700 and even to 1000 cubic yards per mile per annum.

Very interesting comparisons could be made of the wear of roads under different circumstances if accurate data could be obtained of the amount of material applied in repairs, and of the traffic passing over a given length in a given time.

To add still further to the difficulties which beset this subject, the nature of the subsoil and the condition of the drainage have to be taken into consideration, while the quantity of the material employed for repairs is a factor which enters largely into the question.

To exemplify how much depends on the quality of the metalling made use of for repairs, and, consequently, the number of cubic yards applied on each mile of road during a season, the following particulars may be given:—

Previous to steam road-rolling being introduced, the different lengths of roads under the author's jurisdiction were maintained on the patching system with road-stones from various quarries, the material from the nearest local source being generally employed.

One of the sections of road referred to, although in very good condition, was entailing a greater cost for maintenance per mile than other portions of the same road under similar conditions as to traffic, gradients, and exposure to the action of the sun's rays. The surface and subsoil drainage were examined, but as they were found to be in good order the cause of the difference had to be sought for elsewhere. The amount of scraping and cleaning was much greater in proportion to that on the adjoining portions of the road, while the annual consumption of metalling was relatively much higher. This clearly pointed to the quality of the road-stone, which was to all appearance of a suitable nature, but did not give equal wearing results under traffic. The metal of which this particular section of the road was repaired cost 4s. per cubic yard deposited in depôts, the quarry being situated within an easy carting distance.

The quarries yielding the material for repairing the adjoining sections of the road were situated at a considerable distance, but under the circumstances it was considered desirable to rearrange the source of supply from which the metalling for the portion of road referred to should be obtained.

To supply stones from the other quarries involved an additional cost, principally for haulage, the average price being 5s. 6d. per cubic yard. The quantity of metalling applied each year previous to this was 150 cubic yards per mile, which meant at that quantity an additional annual outlay of £11, 5s. for road metal alone.

It was observed, however, that in the course of two years the condition of the surface of the road was such, and the manual labour had decreased so greatly, as to warrant the annual amount of metalling for repairs being reduced by 50 cubic yards per mile of road.

It is obvious that by the judicious application of a durable material, economy in the cost of maintenance is ultimately attained, while the condition of a road is improved, and the tractive effort of horses reduced. The actual cost of maintenance, including labour, in the case mentioned was, by substituting a better quality of macadam, reduced by £5 per mile, which at first sight does not appear a great saving, but, assuming the principle to be applicable to many miles of roads, under similar conditions to those in the one pointed out, the annual expenditure might, in many instances, be considerably reduced.

For this reason and many others, and with a view to efficient labour and attention to drainage, comparisons should be made of the annual expenditure on different sections of roads similarly situated, so that when excessive differences arise the whole expenditure may be analysed in detail, and the causes of the apparent discrepancies ascertained.

309. Cost of Maintaining Roads.—The annual cost of maintenance per mile of roads, like the quantity of metalling applied, is a very variable figure, and depends on the amount of wheel traffic, the quantity and quality of the material employed for repairs, the distance of the source from which it is obtained, the situation of the roads being open or otherwise, and with favourable gradients for efficient drainage, and the cost of labour in the particular district under consideration.

A road repaired with suitable material on a well-drained subsoil, exposed to the action of the sun and air, and over which there is a moderate amount of traffic, may be maintained for a trifling sum for each mile per annum. On main roads, however, where the wheel traffic is much heavier, the annual cost for maintenance may vary from £20 to £70 per mile, while on suburban roads and those situated between large cities, the cost per mile may range from the latter figure to £200 or £300 per annum.

310. It is stated, on the authority of Mr. Browse, that in 1856 the cost of the yearly maintenance of the road over Westminster Bridge (which, since that time, has been paved with causeway setts, and is now laid with wood blocks) was at the rate of £3300 per mile, the average wear of the granite macadam being 5½ inches. Other figures give the annual cost of maintaining macadamized roads on some of the streets in London noted for their incessant and exceedingly heavy traffic, which have since been paved with setts or wood blocks, at 2s. 9d. to 3s. 6d. per square yard. It is, however, necessary to bear in mind that the cost of the metalling (Guernsey) is 14s. to 18s. per ton delivered in London.

311. Relative Proportion of the Combined Cost of Maintenance.—The relative proportion of the outlay on manual labour and material to the combined cost of maintenance will vary according to the requirements of road and the price which is paid for the macadam, the distance hauled being an important factor in the case.

On light-trafficked roads the cost of manual labour will be increased in proportion as the amount of material applied becomes less. In the case of these the cost of manual labour ranges from 40 to 50 per cent. of the combined expenditure, while the proportion, when the quantity of material employed each year is from 100 to 200 cubic yards per mile, procured at an average cost, may be only 25 to 30 per cent. of the combined cost.

In the case of some of the busy thoroughfares in London, where the quantity of metalling applied on the roads each year exceeded 500 cubic yards, and the annual expenditure was about £400 per mile, the proportion of labour probably did not exceed 18 per cent. of the combined cost.

It may be observed that on country roads the average cost of maintenance varies considerably. Many roads or sections of a length of road are kept in good order for £7 per mile per annum, while on roads over which a heavy wheel traffic passes the yearly expenditure for maintenance on short lengths may cost £100, £200, or even £300 per mile.

312. **Methods of Repairing Roads.**—The repairing of the surface of roads may be carried out either by placing new materials in thin coats and small patches year by year, known as the 'patching' system, or by spreading a coat of metalling of varying thickness, according to requirements, and consolidating the material by steam-rolling.

In the former case the loss by wear caused by the wheel traffic and weather is replaced annually. In practice it is found that the wear and the thickness of the material composing the crust of a road are very irregular, consequently it often happens that under certain circumstances portions of a road are coated more frequently than others which are more favourably situated.

The new materials should be spread on the parts of a road which require them, namely, in hollows or depressed and weak places, with a view to making the most frequently traversed portion of the road as far as practicable of uniform strength. The number of years which will elapse before the whole wearing surface of a road will be covered, assuming it to be of a nearly uniform strength throughout, will depend chiefly on the amount of vehicular traffic passing over it, and the quality of the metalling employed. The number of cubic yards, therefore, which it is necessary to spread over the surface in patches on a stretch of one mile of road each year in order to keep it in proper condition, will depend on the requirements in each particular case.

313. The area which one ton of screened road-stones will cover depends on the size to which they are broken and the specific gravity of the stone. Macadam broken to 1-inch gauge contains 52 per cent. of solid to 48 per cent. of interstitial vacant space; 1½-inch material, 51 of solid and 49 per cent. of interstitial space; 2-inch stones, 50 per cent., and 2½-inch metal, 49½ and 51½ per cent. of solid and interstitial vacant space respectively.

A cubic yard of screened road-stones broken to 1-inch gauge and spread one-stone thick will cover about 45 square yards; 2-inch gauge metal 27 square yards, and 2½ inch gauge macadam 24 square yards.

In coating a road which is to be rolled the quantity applied may be one stone in depth only; it is, however, invariably spread to a thickness of from 3 to 4 inches. When two or three stones in depth are applied the covering area is less in proportion to that stated, owing to the material being more compact in a coating of some inches in depth compared with a single-stone layer.

As the haulage of the material is usually paid for at a ton-mile rate the cubic yard is seldom employed now in road-work, although a comparison can be easily arrived at.

Specific gravity depends on the mineralogical composition and compactness of rock, the more basic varieties being the heavier; consequently a small variation in this direction makes a considerable difference in the covering capacity of a ton or cubic yard of road-stones.

For instance, a road-stone having a specific gravity of 2·5 contains 14·336 cubic feet per ton of solid rock as found by the formula $\frac{2240 \times 16}{1000 \times \text{specific gravity}}$, and from this can be calculated the number of square yards which a ton of broken stones of any gauge will cover. In the case referred to it will be found, assuming 1 inch as the depth for the purposes of calculation, that one ton will cover an area of 38·6 square yards, allowing 50½ per cent. as the average proportion of solid stone for 1½ to 2¼-inch gauge screened macadam. Road-stone having a specific gravity of 2·75 will under similar conditions cover an area of 35·5 square yards, and macadam the specific gravity of which is 3·00 will cover an area amounting to only 32·25 square yards.

This represents a difference in covering area of about 6 square yards in favour of the lighter stone at 1 inch in depth; or, with the customary coating of 3 to 4 inches, the difference is 2 to 1½ square yards more in covering power than the heavier road-stone.

314. The most reliable road-stones, however, have a specific gravity greater than 2·5; indeed, many of the best varieties range from 2·75 to 3·00, although there are some notable exceptions. The specific gravity of a rock is no indication of the quality of a road-stone, but the heavier it is the less area will it cover in proportion to a lighter stone.

Most of the road-stones used by the author have a specific gravity of about 3·00; therefore 32 square yards is the figure adopted for 2 to 2¼-inch road-stones, which represents the area or surface covered at a calculated depth of 1 inch. The area which one ton of road-stone will cover can be ascertained by dividing this figure by the depth of metalling, in inches, to be applied.

Screenings from a stone-breaker of an average size of ¼ to ¾ inch weigh, at the specific gravity mentioned, about one ton to the cubic yard, while the smaller size, or ¼-inch, and dust weigh 23⅓ cwts. to each cubic yard.

The number of square yards of surface which can be covered when the quantity of material which is allocated to each mile of road is known, can be ascertained from these figures. Thus on a road 15 feet wide, with an annual supply equal to 175 cubic yards of macadam per mile, each part of the road would be coated once every two years. Taking the quantity of metalling at 40 cubic yards per mile per annum with the same width of road, it would take a period of nearly nine years before the whole surface could be coated. On a roadway 30 feet wide, the whole surface would be covered every two years with a quantity of 350 cubic yards per mile each year, or every four years with an annual supply of 175 cubic yards per mile.

It is evident that certain parts of a road must undergo wear for many years without needing to be coated, while it is obvious that certain parts of the road repaired by patching must necessarily be less strong than other portions. The road may be able to withstand the ordinary traffic, but in the event of excessive or exceptionally heavy traffic coming upon it, combined with bad weather, the crust of the road, especially where the next annual coating of metal will in all probability be spread, would suffer owing to its weak state of repair. Heavy weights traversing a road, irrespective of its strength to bear them, cause considerable damage, and in all probability reconstruction may be necessary in many instances.

315. In applying small coatings of metal, it is usual to spread a patch alternately on either side of the crown of the road, and, when necessary, on the centre, leaving a sufficiently clear space between the coatings so as to 'force' the vehicular traffic to follow a winding track, while the horses' feet can avoid coming in contact with the stones. This means of consolidating the freshly-laid metalling is naturally avoided where possible by those using the roads, so that the remainder of the road surface will receive an undue share of the traffic, with the result that considerable wear is caused in places least able to bear it. By exercising care in the spreading of the metalling, which is to be worked in by the wheels of vehicles, and attention to the patches during the process of consolidation, great annoyance and inconvenience to those using the roads may be avoided; while the damage to horses and vehicles resulting from this cause may be reduced considerably.

The patches of macadam which are to be consolidated by wheel traffic should not exceed 4 to 5 yards in length, and from 1½ to 2 yards in width. In order to ensure the gradual working in of the metalling by the wheels of vehicles, it is desirable to spread a quantity of the small material round the edges of the metal patch. This will enable the wheels of vehicles to work gradually from the sides to the centre of the patch.

The practice of stocking the surface or loosening the old material with picks where the new macadam is to be applied is seldom resorted to.

Generally the weather prevailing during the winter months in this country presents but little difficulty to the process of incorporating the new metalling with the old surface by ordinary wheel traffic, although the time occupied in consolidating the macadam may vary from two to five months.

316. Time of Year when Repairs should be carried out.—The precise time at which to commence applying the road metal will depend upon the climate, weather, the nature and strength of the road, and the class of material employed. The autumn and early winter, provided the surface is in a slightly soft condition, is generally the season for applying the bulk of the macadam. On many roads fully 75 per cent. of the material is spread at the first operation, while on some roads, especially those over which there is a heavy traffic, only about 50 per cent. of the total quantity is applied in the first instance. In the latter case, and after the first coat of metalling is well set, a further quantity, amounting to about 25 per cent., is applied generally in the month of January, the remaining 25 per cent. of the total quantity of macadam, which is usually of a small size, being spread in either case about the middle of February or beginning of March; this is known as 'spring patching.'

Should the rainfall during this time of the year be under the average, or otherwise dry, the vexed question of using a binding material will present itself.

Under normal conditions of rainfall, the amount of material for repairs necessary to be applied so as to keep a road in good condition will, apart from the amount of wheel traffic, be greatly affected by the weather. When the quantity of macadam used per mile of road per annum is determined in relation to the position the road occupies, the amount of wheel traffic which in ordinary circumstances traverses it, and the average rainfall, there should be little difficulty, by judicious management, in having all the coatings thoroughly set by the beginning of April each year. During a dry season, however, although the surface of the road was in suitable order when the metalling was applied, a binding of some kind is necessary to retain the stones in position, if not also to aid the consolidation of the coatings. Binding, or rather 'blinding,' should not be spread over macadam lying in a loose open state, otherwise the surface will become rough, and the ultimate wearing capacity of the coating be greatly reduced. Generally speaking, binding should not be applied to the metalling unless the coatings are partially set or consolidated, and then only during the spring months, in order to give a smooth surface, and preserve the macadam from being crushed; but it may be absolutely necessary to apply it owing to the absence of moisture to effect this properly.

317. The practice of using blocks or trestles to force the wheels of vehicles on to the patches of road-stone is a primitive method of aiding consolidation, but one which, under adverse circumstances, is inseparable from the mode of repairing roads by means of spreading isolated patches of macadam on them. The use of these should be restricted as much as possible, and resorted to only when damage is likely to occur by reason of the vehicular traffic running in one track after the supply of metalling is exhausted.

318. Composition of the Crust of a Road.—The composition of the crust of a road that has been repaired by a system of patching is made up of a high proportion of detritus in combination with the metalling forming the wearing surface.

Experiments have been made to ascertain the composition of traffic-consolidated road surfaces, or the proportion of solid material to that of voids or spaces filled with small stuff or muddy cementitious material.

Observations on metalling broken by hand to pass through a $2\frac{1}{4}$-inch ring show the average proportion of solid to void to be 56 per cent. and 44 per cent. respectively.

During the process of consolidation by the wheels of vehicles, a considerable amount of the material is reduced to dust and small chippings. This waste, brought about by abrasion, is estimated by some authorities at 30 per cent.; to a certain extent it assists in filling the voids of the macadam, and in the consolidation of the coating. The greater portion of this waste is, however, scraped off the road in the form of mud.

If a portion of a well-kept wheel traffic made road, repaired with hard whinstone or basalt, be taken up, and the component parts of the sample separated so as to exclude all material which will pass through a half-inch riddle, a size that may be fairly considered as exhausted macadam, it will be found to contain on an average 56 per cent. of solid and 44 per cent. of void or detritus.

This proportion, it may be observed, is nearly similar to that of the original metalling.

Mr. Codrington, when acting as Superintendent of the County Roads in South Wales, carried out many experiments in connection with the composition of road coatings on roads repaired with different kinds of material.* The average results he obtained show that 39 per cent. of the material composing the constituent parts of the crust was made up of stones over $\frac{7}{8}$ths of an inch in size, 44 per cent. of small stuff from less than $\frac{7}{8}$ths to $\frac{1}{30}$th of an inch, while 17 per cent. consisted of detritus or mud. This is practically equal to 39 per cent. of solid or serviceable material and 61 per cent. of void or small exhausted macadam and mud, although in some cases the proportion of solid to void was nearly equal. The material was originally $2\frac{1}{4}$- and $2\frac{1}{2}$-inch metalling, but was principally composed of mountain limestone, a material not used now to any great extent.

He also states that specimens of consolidated limestone roads weigh from

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* *The Maintenance of Macadamized Roads*, by Thomas Codrington; second edition, 1892, pp. 54 and 55.

161 to 163½ lbs. per cubic foot, when the limestone of which they are repaired weighs 171½ to 172 lbs. per cubic foot, the consolidated road being thus 93½ to 95½ per cent. of an equal bulk of solid stone. The same proportion was found to prevail on consolidated road surfaces composed of metalling prepared from igneous rocks.

When the metal coatings of roads contain a large proportion of mud and small-sized stones, such roads will not be capable of withstanding the wear caused by the passage of heavy traffic during wet weather, or when the crust of the road is in a soft state. Alternations of frost and thaw on such roads will likewise destroy the coating and reduce the better portions of the metalling quickly to detritus, more readily than in a road the constituent parts of which are mainly composed of serviceable material. Under the latter conditions, and with efficient surface and subsoil drainage, these atmospheric influences have but little damaging effect.

The inconvenience experienced, and the great waste of material inseparable from the old method of repairing roads by patching, however well carried out, cannot be compared with an efficient system of steam rolling, and this mode of repairing roads will now be described in detail.

319. Steam Rolling as applied to Repairing Roads.—In many countries the methods practised in obtaining the material, the subsequent means adopted in reducing the rock to macadam, and steam rolling, are carried out on thoroughly scientific principles. Apart from the great advantages to those using the roads, and which are of primary importance to owners of horses, a considerable economy in the maintenance of the roads, compared with the old system of performing the work, can be shown to result from the employment of an efficiently equipped road maintenance plant.

The construction of the steam roller has been already described, and no matter what the weight of the engine employed to perform the work of consolidating the metalling may be, the method is precisely the same, although the cost of rolling will be somewhat higher when rollers of the light class are made use of.

A system of rolling practised in some of the counties in this country is that of consolidating the metal patches which were formerly allowed to be worked in by the ordinary wheel traffic.

The area to be covered is generally loosened by means of hand picks, or by a scarifier, previous to the new metalling being applied. In most cases, however, the edges of the worn-out parts to be renewed are only loosened, so that the macadam forming the outside of the patches will not be crushed by the roller wheels during the process of consolidation.

If the surface of a road contains a considerable amount of detritus or is previously softened by artificial watering, the macadam, which can only be spread one stone thick in this method of repairing, may be consolidated without much damage being done to the metalling. Under ordinary circumstances, however, the portions of the road to be repaired should be picked or scarified, otherwise the macadam will be, to a great extent, pulverized by being placed between two hard materials, namely, the surface of the road and the roller wheels. In rolling patches of metalling it is necessary to sprinkle water over the surface to aid consolidation, the detritus in the old macadam being generally sufficient to form a binding for the new coating. This is swept over the surface; then, by repeated passages of the roller with occasional watering, all the interstices of the stones are filled up and the surface is made perfectly hard and smooth.

This method of improving the surface of roads is undoubtedly a very decided advance on the barbarous system of consolidating the macadam by the wheel traffic formerly resorted to, and which, unfortunately, is still in operation in many districts at the present time. It must be admitted as a general principle, however, that when rolling patches of metalling, the whole width of the roller wheels cannot be brought into use simultaneously or continuously. For very small repairs, or on roads which have been rolled and are slightly out of repair at places, the process of mechanical scarifying, applying a small quantity of fresh road-stones, and rolling, improves a road surface materially, and it may thus be made nearly equal in durability and appearance to a road which has been coated and consolidated.

320. Rolling Patchwork.—The following is an instance, and the remarks are applicable to a greater or less extent in rolling all metal patches.

When a patch of metalling, 3, 4, or 5 feet in width, has to be consolidated, the effect of rolling is such that a part of the breadth of the engine wheels overlaps the metal patch, consequently that part is doing no actual work so far as consolidating the new coating of metal is concerned. It has been already stated that the rolling width of a 15-ton roller is 7¼ feet, while in one of 12 tons weight it is 6½ feet; hence, to obtain the advantage of the full effective width of a roller the breadth of the metal patch would require to be increased accordingly. This, in effect, means adapting the extent of repairs to the rolling width of the engine, irrespective of the actual necessities of the road. Assuming, then, that this has been satisfactorily arranged, the length of the metal coating has to be considered, and it may happen that by this system of working the new material is spread with but little space between the patches, which will admit of the maximum amount of surface area of metalling being rolled. It is obvious, nevertheless, that as the roller commences work clear of the metal patch, or on the old portion of the road, which process is repeated each turn the engine makes, and also overlaps the width, a considerable amount of the benefit of rolling is wasted on the portion of a road which is probably in excellent order. In other words, the cost of rolling patches of metalling is considerably greater than when continuous coatings are spread to the full width.

The author has found from experience that 30 cubic yards of metalling spread in isolated patches can be consolidated in one day during the autumn and winter months with a 15-ton roller.

321. Cost of Rolling Patches of Metalling.—The cost of rolling thin coatings of metalling applied on the patching system, including sweeping, and water-cart horse, but exclusive of spreading the macadam, is 9d. per cubic yard. It is necessary to add, however, that in some cases many of the patches were partially consolidated by the wheel traffic previous to the work being undertaken by the roller.

The County Surveyor of Nottingham * has carried out the patching system of repairing road and steam rolling on an extensive scale for some years past with good results.

He uses 12-ton rollers, and the average cost of consolidating the metalling, including small repairs to the plant, is 9d. per ton. This is an average for working all the year round, the operations being carried on during the summer months on the roads which are nearest the best supply of water.

This system is mostly followed where limited quantities of road-stone are applied annually, and especially when the cost of the material reaches a high figure, the object being to obtain a smooth surface; a road so treated, however, would not have a reserve of strength capable of withstanding fluctuations of traffic.

The quantity of material spread in patches which can be consolidated by a roller each day under ordinary circumstances is on an average 30 tons; in many instances, however, 20 tons may be considered good work, especially where the exigencies of the passing traffic necessitate frequent stoppages during the operations.

322. Rolling Continuous Coatings of Metalling.—For the reasons given, and because of the time lost by the roller travelling to distant parts of a district repeatedly year after year, the author prefers to consolidate coatings of metal in long stretches spread to the necessary width, as the experience gained in carrying out the two systems clearly shows that in the latter method there is greater economy in working expenses as well as increased efficiency.

The roads are also more uniform in strength, while a more regular wearing and durable surface is obtained by a system of continuous coatings consolidated by steam rolling.

The additional quantity of metalling necessary to keep a roller constantly at work in some districts might, at first sight, be considered a serious obstacle to the introduction of road-rollers on economical grounds alone. No doubt this would be the case if, in addition to the annual quantity usually allocated for patching purposes, a great amount of metalling were supplied to coat long stretches, or otherwise to ensure the roller being continually employed.

By adopting a graduated system, however, so that certain roads, to be rolled in the course of a period of three or four years, may be arranged for in advance and added to as the work proceeds year by year, the previous annual quantities of material applied to these roads can, by judicious management, be reduced considerably in view of a thorough repair being undertaken within a limited period of time.

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* A paper read before the Incorporated Association of Municipal and County Engineers, vol. xxii., on "Steam Rolling," by E. Purnell Hooley.

In working out this system of concentrating the metalling, due consideration must be given to the requirements of particular roads and certain sections of a road, where circumstances indicate that attention and the application of macadam are necessary to prevent the crust of the road becoming destroyed. It is advisable, not only when rollers are being introduced for the first time, but as rolling operations are extended, to prepare a list of those roads which it may be considered necessary to undertake in the first instance, and those to be dealt with in rotation later.

The roads, extending probably many miles, which it is intended to roll during the season following the previous year's supply of metalling, should be repaired by only employing the quantity of material that is just sufficient to maintain a fairly good surface without allowing the road coating to become tracked.

By this means, and when the following year's supply is prepared, a quantity of macadam nearly equal to two years' ordinary allocation is thus reserved until the rolling operations are commenced. This arrangement may be extended so that a three or four years' supply may be applied and rolled on any particular road.

As a means to an end, this is the only method which can be followed, unless larger quantities of material can be procured at a cheaper rate. Methods have been described in the chapters on Quarrying and Stonebreaking, by which material can be procured at a small cost.

Undoubtedly a country road can, by careful attention, be kept in good repair with a small quantity of material for a limited period of time, and by allocating a quantity of macadam, to be applied only when the road shows signs of giving way, a large amount of metalling may be reserved and concentrated on roads where found necessary in connection with rolling operations. Adverse weather in the form of alternating frost and thaw, will no doubt injuriously affect certain portions of the road surface, but apart from a trifling expenditure in labour to remedy this, the weak spots can be specially treated previous to or at the same time as the general repairs are carried out.

It has already been shown that under the old system of repairing roads by patching and consolidating the coatings by wheel traffic, a layer of macadam one stone thick serves to bear the ordinary traffic without failure of the road surface for a considerable number of years. Any reduction, therefore, of the annual quantity of metalling applied, as a temporary measure, will not materially affect the strength of the road for a time.

Experience shows that by judiciously arranging the annual allocation of material for repairs, the actual quantity previously used can be reduced by 75 per cent., when rolling operations are to be undertaken the following season, and 50 per cent. in the case of roads which are to be rolled the second year. On these roads which are to have attention during the third season, a quantity of metalling amounting to a 25 per cent. reduction on the former quantity applied will be sufficient for ordinary repairs. It is obvious that by this method of reducing the quantity of road metal, in advance and in regular rotation, a sufficient supply of material will be provided to keep the roller employed in consolidating either large patches of metalling, or wide continuous coatings. It may be well to state here that a reduction in the quantity of metalling used, when spread in continuous stretches and rolled, will give a saving of about 25 per cent. of the total amount formerly applied in patching which was consolidated by vehicular traffic.

If the macadam used for repairs is hand-broken, it can be stored in depôts or brought direct from the source of production to the road under repair, care being exercised to avoid unnecessary haulage, which, besides entailing extra cost, does not add in any way to the efficiency of the work.

It happens at times in some counties that a supply of suitable material cannot be obtained in the immediate neighbourhood of the roads to be repaired. This may necessitate the metalling being brought from a considerable distance, even from points beyond the limits of the county where the operations are to be carried out. In such circumstances the cost of maintaining the roads is considerably increased, owing to the high rate paid for haulage by rail or otherwise, which often amounts to three or four times the initial cost of the macadam at the source of supply.

323. Example of the Methods adopted in Arranging for Rolling Operations.—Where quarries exist the rock of which is suitable for producing road metal, and are so conveniently situated in relation to the road where the repairs are to be made that the material can be conveyed by carts or by traction engines and wagons, the following method of arranging the work is usually adopted.

The fixing of the portable stone-breaking machine and all the other accessories being arranged as described in Chapter VI., the points on the road at which the supply of metalling should commence and terminate from the different quarries may best be illustrated by giving an example taken from actual practice.

A road, A B, fig. 126, extending to 5 miles, was repaired by a continuous coating of metal, the width ranging from 14 to 18 feet, while the depth of the macadam varied from one stone thick to 4 inches. The section A *d*, of the main road A B, had been previously maintained with material of a hard and tough nature, over which a heavy traffic passed. The surface of the road was considerably worn, which necessitated a coat of metalling 4 inches thick being applied.

The section *d e* was repaired with the same material as the previous section, but the traffic passing over it was of a moderate description; the repairs being effected by scarifying the old surface, bringing it into proper contour, and applying a coat of metalling one stone thick. The section *e* B, the wheel traffic over which is considerable, was maintained with a material of a highly siliceous nature, while the surface had become badly cupped, necessitating the coating being scarified and the old material screened to remove the high percentage of small or exhausted material.

This small stuff was laid aside and used afterwards for binding the new metal coating, the thickness to which the macadam was laid being 3 inches between *e f*, and 4 inches between *f* B.

The quarries from which the metalling was taken are marked *a*, *b*, *c* in fig. 126.

In deciding from which of the two quarries *a* and *b* the material should be taken for repairing the portion of the section from A towards *d*, the rock being of equal quality, the relative distances and the probable expense of working had to be taken into consideration.

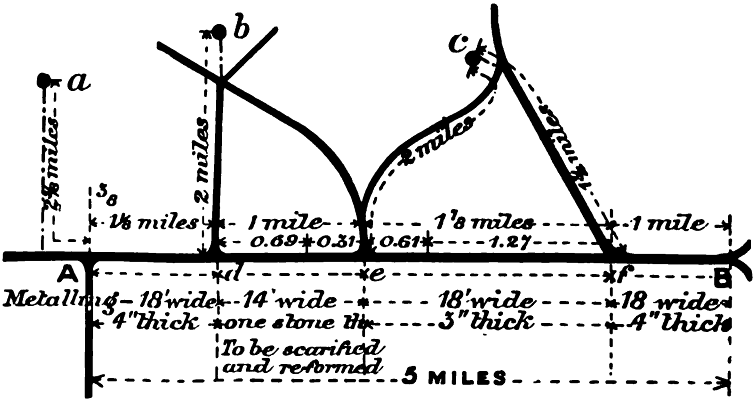

FIG. 126.—Plan showing how to economize haulage from quarries to main road.

The conditions as regards the access to, and the service roads leading from both quarries were very much alike, consequently the cost of haulage per ton-mile did not enter into the question.

The point to be decided was the distance from the points *a* and *b* to the commencement of the section at A. On referring to the measurements on sketch plan, it will be seen that, so far as the mileage is concerned, the quarry *a* would, for a distance of ⅜ths of a mile from A towards *d*, be the preferable one so far from which to procure the material for repairs. The quantity of macadam required for this section A *d* of the road, to the width and thickness of coating shown, would be 495 tons, which could be accomplished in about nine days by means of a stone-breaking machine.

Subsequent to breaking this quantity of macadam the stone-breaker would require to be removed to the quarry *b*, so as to equalize the cost of haulage; but the removal of the plant from the quarry *a* to that at *b*, including dismantling and re-erection, would entail an expenditure of 50s. The cost of production therefore would, considering the short period which the plant was required at quarry *a*, be enhanced by about 1¼d. per ton, compared with the cost had the breaking machine been set to work in quarry *b* in the first instance.

The expense of one change or removal was thus avoided, and although the haulage cost more, the total expenditure incurred in repairing the section A *d* was less by procuring and breaking all the metalling required from one quarry, instead of, as contemplated at first, dividing the quantity between the two quarries *a* and *b*. The cost of removing the plant from one quarry to another is infinitesimal when calculated at so much per ton on a large quantity of material, while it is considerable when only a few days' breaking is undertaken, by reason of the high proportion of the time required for removing the machinery, to the actual amount of work performed. In other words, the additional cost for breaking by machinery amounts to 1¾d. per ton when the plant is removed each week, while it is under ½d. per ton of macadam broken, if a month's work be accomplished before commencing operations in another quarry, compared with a longer period of time.

It will be obvious from these considerations, that the most economical arrangement was to procure the whole material necessary for repairing the section of road mentioned exclusively from the quarry *b*.

The points *d* and *e* on the road, being situated exactly at the same distance from the quarries *b* and *c*, would, if the conditions were equal, present no difficulty in fixing on the point as that midway along this section, where the cost of haulage from either quarry is equal.

The road from the quarry *c* is of an undulating nature, however, which involved an increase for haulage of 1¼d. per ton-mile compared with the cost of haulage from the quarry *b*. The question presents itself in this way: at what point between *d* and *e* does the cost of haulage from either quarry become equal? This is simply a matter of calculation. With regard to the section *e f*, similar conditions as to haulage existed, and the road from the quarry *c* to B being on a gradual descent, the price per ton-mile for haulage was similar to that from the quarry *b*, namely 7¾d. As in the preceding case, it is necessary to calculate the cost of conveying the metalling, so that where the materials applied to the road from the two quarries meet, the expenditure for haulage in either case will be the same.

The spreading of the macadam, and therefore the rolling, should be commenced at the part of the road to be repaired which is farthest from the source of supply; that is, when breaking in quarry *b*, the repairing of the road should be commenced at the point A, and be continued towards *d*. The portion of the section *d e* should likewise be arranged for by fixing the point where the operations are to be commenced, and working back to *d*.

324. Haulage—how arranged.—By arranging the work in this manner the carts or wagons employed in conveying the metalling do not pass the roller, and therefore do not interrupt the work of consolidating the metalling.

In conveying the road metal by team labour direct from the stone-breaking machine, or even when taking it from depôts, tip-carts only should be employed in depositing the macadam on the road, as by so doing the men spreading the material can regulate the supply when being emptied, and so save extra labour in handling.

The macadam is thus placed approximately in position, but all the material should be turned over by shovels so as to equalize the coating. With well-screened metalling less time is necessary to accomplish this than in the case of spreading hand-broken stones or material containing a large proportion of small or of irregular-sized stuff; it is necessary in either case, however, to employ thoroughly experienced men to perform this work, as the future durability of the coating, although rolled, will greatly depend on its having been properly executed.

The spreading of the metalling, as already stated, is commenced at the point furthest from the quarry, and when a stretch of about 30 to 50 yards of road has been coated the rolling is commenced.

To ensure that the proper quantity of macadam is being applied to the road, the area spread each day should be measured. On referring to the weigh-book, the total quantity of material removed from the breaking machine and deposited on the road is ascertained, when it can be easily verified if the proper depth of metalling is being adhered to.

325. Binding Material and Artificial Watering necessary.—Previous to, and during rolling operations, binding material should be prepared from the road sides, if suitable, or brought from the nearest available source, and deposited conveniently on the bermes or in the water-tables on either side, and all the water outlets should be closed.

The rolling, as explained in Chapter VII., is commenced at either side nearest the water channels; the engine is worked gradually towards the crown of the road, and repeated passages are made in order to set or interlock the macadam, during which process the flat sides of the stones are brought uppermost. After this has been accomplished, and then only, the artificial watering is commenced, when, according to the nature of the material and weather prevailing, the binding is applied; the new metalling being wet prevents its being 'licked up' by the roller wheels.

When clean sand is the material made use of for this purpose, it should be spread over the partially rolled metalling evenly and in small quantities as the roller passes backwards and forwards, the interstices being gradually filled by watering and sweeping, until the whole surface is thoroughly consolidated and presents a mosaic-like appearance. If sand is applied before the metal coating is well set, it will be washed to the bottom of the macadam and cause trouble afterwards. When the binding material is composed of loamy sand, road-drift, or road sweepings, from which the vegetable matter has been removed by being properly weathered, the system of working adopted on roads up to 18 or 20 feet in width is to convert the binding in the water-tables into grout by a copious supply of water, and passing the roller wheels over it. The binding, in this consistence, is then swept from either water-table towards the crown of the road, when by the repeated passing of the roller the whole body of the macadam is bound together. The process of rolling with a slight watering should be continued even after the surface appears to be consolidated, as by this means any surplus binding lying in the interstices of the stones will be squeezed out, and should be removed by sweeping to the sides.

326. **Amount of Rolling necessary.**—The amount of rolling necessary will greatly depend on the nature of the material and binding used, therefore no specific rule can be laid down; experience and observation are the only reliable guides.

Generally speaking, a sufficient degree of consolidation will be attained when the stones cease to creep or move under the action of the roller wheels.

A method of testing sometimes adopted is placing a single piece of road metal on the surface of the newly consolidated coating; should the stone be crushed to pieces instead of being forced into the general body of the road, a sufficient degree of hardness is considered to have been attained. This may be applicable in some cases, but as the quality of the metalling depends on this method of determining the degree of consolidation, it is not a very reliable test.

As all binding material contracts after the moisture evaporates, the metalling at the surface, especially during dry weather, becomes slightly loose. It is necessary, therefore, to apply some light binding material to counteract this tendency, for which purpose a thin coat of sand ½ inch thick spread over the surface is particularly useful, but during high winds it is easily blown away, leaving the surface of the road bare and unprotected.

The best material which can in any circumstance be applied is, in the author's experience, the fine chips or screenings from the stone-breaker, which, being of some weight, are not so liable to be thus disposed of.

These binding materials should be applied immediately after the rolling proper is finished. It is advisable and, in most instances, necessary, on the advent of rain to send the roller over the newly finished road again. By doing so, every advantage is brought to bear on the metal coating, as the lower part of it, being in a partially moist or green state, and the surface covered with a thin layer of chips, the whole mass is thoroughly compacted and a smooth hard surface formed.

This produces a 'skin' capable of resisting, under most circumstances, the destroying influence of dry weather and traffic on a newly rolled road, especially when the binding material used is of the kind mentioned. In the absence of rain it may become necessary to apply artificial watering to ensure a properly finished surface.

These remarks apply where in the rolling operations there is used only as limited a quantity of binding as possible, consistent with the proper cohesion of the macadam, and not to the system of using unsuitable material for this purpose, applied in immoderate quantities, which will give so much trouble in the subsequent maintenance of a road.

327. Hand-broken road metal applied without being screened, especially when the proportion of small material in its bulk is large and rolled in the usual way, presents a cupped surface in a few months after the work is completed. This is brought about by the material not being of a uniform size; the spreading of it equally over the surface of the road is a very difficult matter indeed; and should the metalling be prepared from rock of a highly siliceous nature, or acid variety, the process is well-nigh impossible.

The traffic carried on narrow wheels will in a short time wear out the parts where the small material has been spread and cause hollows to be formed, owing to its not being equal in strength to the proper sized macadam composing a portion of the coating.

A greater quantity of ordinary hand-broken metalling can be consolidated by a roller in a day than when machine or screened hand-broken is employed. In other words, the cost of consolidating ordinary hand-broken macadam is less per ton than when screened material is used.

328. Method of Applying Scarifying Machine.—A machine for scarifying the surface of a road is a very valuable adjunct to road-rolling, and may be applied in various ways. Many old roads containing a sufficient amount of metalling, and over which the traffic is of a light description, can be scarified 3 or 4 inches deep, brought to a uniform contour, and rolled, so as to present a smooth and hard surface. This may be carried out at a trifling cost, and will effect the improvement of making a good serviceable road of one previously in an unsatisfactory condition. The operation, whether for improving an old road or for the purpose of applying a light or heavy coat of metalling, is carried out in a similar manner.

The first cut when using Morrison's scarifying machine is commenced at the side and continued towards the crown of the road; then the engine is reversed, and the work done on the other side. The scarifying is best performed in the early morning, when, as a rule, passing vehicles are not so numerous. Two hours each day is, in ordinary circumstances, ample time for this work in scarifying an area sufficient to admit of the daily supply of material from the stone-breaker being spread over the loosened surface.

It is sometimes advantageous, however, when the consolidation of the new metalling is well advanced, to keep the machine at work for three or four hours, which will be sufficient for two days' rolling. It is not advisable to exceed this amount, except on roads where the traffic is very light, as the passage of the wheels of vehicles partially consolidates the newly scarified surface, especially during wet weather, which involves extra labour; the work must then be supplemented by hand picking.

After the whole surface is scarified, men are employed to rake the material into proper shape, so as to present a uniform contour, any large stones turned up being broken to a proper size previous to the application of the new coat of metalling.

329. Scarifying and Screening the Old Metalling.—The crust of a road which has worn down in a uniform manner is best repaired by applying a coat of metalling without the old surface being scarified. It is usual, however, to run a cut with the machine on either side of the road where the width of the coating is to terminate.

When such conditions exist, it may be considered to be an ideal wearing road. This is only attainable when a tough weather-resisting material has been employed, when the subsoil and surface drainage is perfect, and when the road is open and well exposed to the beneficial influences of sun and air. In most cases it is preferable to scarify the whole surface of the road to be repaired, and when the old metalling is such that the proportion of small material to the full-sized stones is not great, all that requires to be done to prepare it for the fresh macadam is to rake the stones composing the old material into proper contour. This is the simplest method of combining a system of scarifying and rolling, and is the invariable practice where these modern appliances are in use. At first sight this appears to be all that is required, but if a portion of road newly scarified, other than that already mentioned in the preceding paragraph, be examined, it will be found to contain a large quantity of stones varying in size from a ½-inch gauge to the size of a pea, and a considerable amount of fine detritus. On most roads maintained by the aid of wheel traffic consolidation, the quantity of such material, which may be considered the exhausted portion of the crust of a road, amounts to, on an average, from 60 to 70 per cent. of the whole mass.

The quantity, of course, varies greatly, according to the condition of the road surface and the quality of the macadam which has been employed in carrying out the repairs; and in isolated cases the quantity of exhausted to serviceable material has been found to reach as high as 90 per cent.

In the case of roads repaired with a thick coating of metal and steam-rolled, the original proportion of binding to metalling was on examination found to be 15 per cent., and when scarified years afterwards to admit of further necessary repairs, it was found to contain about 40 per cent. of exhausted material. This small stuff, or exhausted material, was determined by what would pass through a ¾-inch riddle or screen.

The reduction in the size of the metalling is caused by the wheel traffic passing over the road wearing the stones, internal friction or abrasion, and by the disintegrating influence of alternating frost and thaw. It may be observed that, even at a depth of 4 inches, a considerable amount of sand or detritus exists. Undoubtedly a large proportion of this is what may be termed 'soft or useless' material incorporated in the crust of the road, which, if allowed to remain when a coat of fresh material is applied, will, after being rolled, give trouble sooner or later, and the result will be the formation of a series of hollows or cups on the surface of the road.

It is obvious that the direct cause of this unequal wearing is the large proportion of small to the ordinary class of material, consequently the irregular sized stones forming the old coating are of unequal strength.

On narrow roads the tendency of the traffic is to keep in one track, causing undue wear, while the other portions of the surface remain in good condition. When once these depressions are formed, the road at these points is subjected to great wear, owing to the surface water being unable to reach the side channels.

To scarify the whole surface under these circumstances is unnecessary. What repairs are required may be accomplished by making one or more cuts with the scarifying machine along the depressed or cupped portions of the surface, applying fresh metalling one stone thick and consolidating by rolling, and a perfectly smooth surface will be the result.

330. When the system of repairing roads is carried out by patching and rolling, the work of consolidation is greatly benefited by previously scarifying the surface of the road. By this method of executing repairs, the material can only be spread one stone thick so as to correspond approximately with the other portions of the road. If the surface of the road is not scarified, considerable damage to the metalling would result by the crushing effect of the roller wheels passing over the metal patches.

It is sometimes the practice to stock the parts of a road to be repaired by means of hand picking, but more frequently the outside edges only are loosened. This process is slow, and, when only partially carried out, results in damage to the fresh metalling; besides, it is more costly than mechanical scarifying.

331. Thickness of Metal Coatings when Consolidated by Rolling.— A matter which deserves careful consideration is the quantity of material which should be applied for consolidation by steam rolling, in order to obtain the best results so far as durability and economy of maintenance are concerned. The amount in cubic yards of metal applied per mile of road, under the old or patching system, is so far a means of determining this quantity approximately. To spread a coat of metalling the full width of a road and to a given thickness, it is evident that so many times the previous annual supply should be applied in order to get good results. The author has found in practice that, to obtain from four to ten years' service from steam-rolled coatings, due consideration being given to the quality of the material used and the situation of the road, an amount equal to from four to six times the average annual supply formerly applied is about sufficient.

Should the crust of a road be considerably worn, or when repairing light-trafficked roads, it is advisable to apply a proportionately larger quantity of metalling, but in no case need it be more than eight times the annual supply allocated under the patching system.

In other words, a road which has been previously maintained in good order by an annual supply of 200 cubic yards per mile of road would require, in order to provide a continuous coating for its full width, 800 cubic yards, or 890 tons, of metalling per mile. As in ordinary maintenance by patching, it is necessary, when carrying out the work by applying continuous coatings, to increase the quantity on the level stretches as compared with the other portions of the road situated on a gradient.

332. Method of arriving at the Probable Cost of Repairing Roads.—In estimating the annual expenditure for steam road-rolling operations, it is desirable to make out a proper statement which should necessarily include the different items involved, from the time the material is quarried till it is consolidated on the road. By this means the actual cost of repairing any section of road can be ascertained, and valuable information is afforded for future reference and comparison. In the following particulars it is the intention to give all the details necessary for framing an estimate for such work, on any length of road or section thereof.

To illustrate this, let the length of road A B, fig. 126, taken from actual practice, be the section requiring repairs; the position of the quarries is represented at *b* and *c*.

As already pointed out, the cost of quarrying the material may vary within certain limits, partly owing to the nature of the rock, but mainly to the amount of the stripping or tirring. Under ordinary circumstances, the inclusive cost of this may be put down at 7½d. per ton of rock sledged, ready to be wheeled to the breaking machine. The items for breaking and rolling must of necessity vary according to the size of metalling required, the capacity of the roller employed, and the available supply of water for carrying on the work of consolidation.

For the road under consideration the breaking of the macadam, including wheeling the rough material to the machine, and all other incidental expenses, may be taken at 11·37d. per ton, while the consolidation of the metalling, including 2d. per ton for spreading the coating, may be safely put down at 9·63d. per ton. The following is a summary of these items.

TABLE XXXV.

	Pence per ton.
Quarrying, including stripping and sledging, ...	7·5 *
Breaking, ...	11·37*
Rolling, including spreading the macadam, team labour for water supply, sweepers, etc., ...	9·63
	28·50

or 2s. 4½d. per ton consolidated.

The hauling of the material will, of course, vary according to the distance conveyed and the nature of the service roads traversed.

The contract price for the section A *d*, in fig. 126, was 7¾d. per ton-mile, the thickness of the metalling applied being approximately uniform throughout the section; therefore the average cost on the length of road A *d* is taken as midway between these points. This average distance is made up as follows:—

Distance from quarry *b* to point *d* =	2·0	miles.
„ „ *d* to A = 1⅛ miles ÷ 2 =	0·56	„
Average distance, . . .	2·56	„

This at 7¾d. per ton-mile is 19·84d., which, added to the total of the other items, amounts to slightly over 4s. per ton.

The next matter to be considered is the quantity of metalling required to coat a road 18 feet wide at an average thickness of 4 inches. It has been pointed out (p. 279) with regard to this matter that the area covered by road-stones varies according to the specific gravity and the size to which the stones are broken. One ton of macadam varying from 2- to 2½-inch gauge, properly screened, which is generally the size of stone adopted in rolling operations, will cover an area of approximately 32 square yards, spread to a thickness of 1 inch.

Therefore at a depth of 4 inches one ton of metal will cover an area of 8 square yards. The area forming the section of road A *d* is ascertained in the usual manner, and will be found to contain 11,832 square yards, which, divided by 8, gives the quantity of metalling required, namely, 1479 tons. The cost of carrying out the work is calculated by taking the latter figure at the price per ton for the inclusive operations, or 4s. 0⅓d.; therefore £298·02 is the cost for repairing this section of road extending to 1⅛ mile.

The second section of road to be repaired from the quarry *b* extends to a point between *d* and *e*. This must be determined previous to commencing operations, for, should the distance be taken as midway between these points, the cost of haulage would, in the case of materials carted from the quarry *b*, amount to 19·38d. per ton, while that conveyed from the quarry *c* would be 22·5d. per ton. To equalize the price for haulage from these two quarries, it is necessary to fix the point on this section of road where the cost of haulage will be the same from either. This may be found by calculation.

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* These figures are purposely made high so as to cover all contingencies which may arise, the actual cost being generally about 5 per cent. less, as pointed out in the chapters on 'Quarrying' and 'Breaking.'

The half-distance between the two quarries along the road is 2½ miles, but as the cost of haulage from the quarry *c* to this point is 1¼d. more per ton-mile than from the quarry *b*, it is evident that the point where the material from either quarry should join will be nearer *e*. The price for haulage is approximately 20·94d., being the mean between the prices from the two quarries at the half-distance. This figure divided by the prices per ton-mile from the quarries *b* and *c* respectively, will give the assumed point, thus: (1) 20·94 ÷ 9d. equals 2·327 miles, and (2) 20·94 ÷ 7¾d. equals 2·702 miles. On examination, however, it is found that the total distance is too great by 0·029 of a mile; to obtain the actual distance to the dividing line it is only necessary to deduct the half of the fractional part (·0145) from each assumed distance in order to arrive at the final result. Thus: 2·702 – 0·0145 equals 2·6875 miles, and 2·327 – 0·0145 equals 2·3125. The distance from quarry *b* is therefore 2·69, and from *c* 2·31 miles. The distance along the section of road *d e* is determined by these figures, being 1214 yards from *d* towards *e*, and 546 yards from *e* in the direction of *d*.

Had the half-distance along the road between the points *d* and *e* been adopted as the dividing line, overlapping would have resulted, and the cost of the work would therefore have been unnecessarily increased, by reason of the extra haulage. Taking the cost of quarrying, breaking, and rolling as before—namely, 2s. 4½d. per ton—an additional sum will have to be added, as this section of the road had to be scarified and re-formed.

The cost of scarifying 3 inches deep may be taken at $\frac{1}{10}$ of a penny; to this has to be added a sum sufficient to cover the expense of raking the material into proper contour and breaking any large stones which may be in the old coating. This is generally equal to about ⅛d. per square yard, consequently these items together amount to 0·22d. per square yard.

The haulage from the quarry *b* to the section of road *d* towards *e* is made up of the distances, 2 miles from quarry to *d* + half the distance to dividing line, which equals ·345, or a total of 2·345 miles. This average mileage at 7¾d. amounts to 18·17d. per ton.

Summarizing these items, the total price per ton for the whole operation on the portion of the section of road from *d* towards *e* is obtained.

Quarrying, breaking, and rolling, ...	28·50	per ton.
Scarifying, forming, etc., 0·22d. per sq. yard × 14, .	3·08	,,
Haulage, ...	18·17	,,
Pence,	49·75	,,

or 4s. 1¾d. per ton consolidated.

The length of the road to be supplied from the quarry *b* is 1214 lineal yards, and as 1 ton of metalling spread close will (according to the rule) cover 14 square yards of road, the quantity of metal required is found to be 404 tons. The total cost of this quantity of metalling, at the price given above, is £83·75. The remaining portion of this section, extending to 546 lineal yards, is arrived at in a similar manner, the quantity of material being 182 tons.

The price per ton for all these items, except the haulage, is the same as in the previous case, namely, 31·58d. The conveying of the metal a distance of 2 miles + ½ of 0·31 mile, or 2·16 miles, at 9d. per ton, costs 19·40d., which is an inclusive price of 50·98d., or 4s. 3d. per ton consolidated. The portion of this section, therefore, will cost £38·67, or a total for the section of road between *d* and *e* of £122·42.

The other sections, *e* to *f* and *f* to B, are proceeded with in the same manner as section *d e*, the dividing line on the former portion being distant 1073 lineal yards from *e*, while the distance from the dividing line to *f* is 2235 lineal yards.

Having thus ascertained the point on the road at which the metalling from the respective quarries *b* and *c* should join, so as to equalize the price for haulage, the cost of the whole work can be estimated.

As the old metalling on this portion of the road contained a considerable amount of small stuff and detritus, it was decided to scarify and screen the material before applying the new coat of road metal. The scarifying, taking it at 0·10d. per square yard, will, allowing 11 square yards for 1 ton of macadam 3 inches thick, cost 1·10d. The screening, including repairs to tools, may be easily performed for 0·27d. per square yard; this is 3d. per ton, calculated on the material which is to form the new coating, making an inclusive price for this work of 4·10d. per ton. Therefore, taking the cost of quarrying, breaking, and rolling as already stated, the total cost is 32·60d.

The average cost for haulage on the portion of the road nearest *e*, at 9d. per ton-mile, is 20·75d. per ton, which, added to the previous items, amounts to 53·35d., or 4s. 5¼d. per ton of metalling consolidated. The quantity of material required for this portion of the road is, for a width of 18 feet, 586 tons, and the cost £130·02. The remaining portion of this section, extending to 2235 lineal yards, requires 1219 tons to form a coat 3 inches thick and 18 feet wide. The average cost for haulage on this portion of the road is 18·52d. per ton, which, added to the other items, gives 51·12d., or 4s. 3d., as the cost per ton of macadam consolidated.

The expenditure for repairs on this portion of road is therefore £259·04.

In regard to the last section of road *f* B, the dividing line is easily arrived at, being the half-distance between the points *f* and B. This averages 2·25 miles from the quarry *c*, which, at 7¾d. per ton-mile, amounts to an average cost of 17·44d. per ton.

The depth of fresh metalling on this section was increased by 1 inch to give a proportionately greater strength to carry the additional traffic from the road towards the quarry *c*. This affected the cost of scarifying compared with the section *ef*; one ton of metalling covering an area of 8 square yards at a depth of 4 inches, so that the cost of scarifying calculated on the new material, 0·80d., and the expense of screening, brings this item up to 3·80d. per ton.

The different items summarized amount to 49·74d., or 4s. 1¾d. per ton of metalling consolidated.

The quantity of material required for a width of 18 feet and of the thickness mentioned is 1320 tons, which amounts to £273·62 for this section.

The total cost of repairing the different sections of road from A to B amounts to £1083·12, being at an average rate of £216·62 per mile.

This line of road has recently been repaired with practically the same quantity of metal. The haulage was, however, carried out by engines and wagons. The total cost of the work was reduced by £126 compared with former estimate.

The arrangement and method of calculating the cost of performing the work has been given in detail, so that the different items may be easily followed; it is usual, however, to make the estimates for this work in a tabulated form, which should be preserved for future reference.

The form shown at pp. 300, 301 is that adopted by the author, experience having proved the efficiency of the method; a sketch plan of the roads to be repaired should form a part of the arrangement, as shown in fig. 126.

333. Cost of Light Repairs.—The cost of scarifying a road 5 yards wide, raking the materials into a proper contour, and rolling, without applying any fresh materials, will cost on an average from £25 to £30 per mile. It is a very significant fact that, when repairing roads by this means, and where the metalling has been consolidated by wheel traffic, owing to the excessive quantity of small or exhausted material, a large amount of detritus is produced in rolling-in the old material again, which should be swept to the sides of the road. In many cases the surplus of soft or useless material, beyond that required for binding in connection with re-forming the surface, amounts to 30 per cent. of the bulk of old metalling operated on.

This large amount of fine stuff or detritus is accounted for by reason of the high proportion of soft to hard material composing the crust of a road when repaired by spreading the metalling in patches, and consolidated by the wheel traffic. It is also augmented by the wear of the material itself.

On rolled roads, when re-faced to improve the surface, where the material used has been of a good quality, the amount of detritus is generally just sufficient to form a binding during the process of rolling-in the fresh metalling, generally one stone thick.

In the case of a narrow road when, as too often happens, the traffic keeps

TABLE

County of................ ; ....

Probable Estimate of Road Rolling,

Division..............from A..............to B..............

Mileage of Road to be Rolled.	Description of Road.	Name of Quarry from which the Material is to be taken.	Cost for Quarrying, Breaking, Scarifying, and Rolling.
Miles 1·12	From, etc., A to *d*,	*b*	Quarrying, ... 7·50 Breaking, ... 11·37 Rolling, ... 9·63 Pence, . . 28·50
0·69	From, etc., *d* to dividing line in direction of *C*,	*b*	Quarrying, ... 7·50 Breaking, ... 11·37 Scarifying and forming 0·22d. x 14, . . . 3·08 Rolling, ... 9·63 Pence, . . 31·58
0·31	From, etc., dividing line to *e*,	*c*	Quarrying, etc., same as above, ... 31·58
0·61	From, etc., *e* to dividing line in direction of *f*,	*c*	Quarrying, ... 7·50 Breaking, ... 11·37 Scarifying, 0·10 x 11 = 1·10 + screening = 3·0, . . 4·10 Rolling, ... 9·63 Pence, . . 32·60
1·27	From, etc., dividing line to *f*,	*c*	Quarrying, ... 7·50 Breaking, ... 11·37 Scarifying, 0·10 x 11 = 1·10 + screening = 3·0, . . 4·10 Rolling, ... 9·63 Pence, . . 32·60
1·00	From, etc., *f* to B,	*c*	Quarrying, ... 7·50 Breaking, ... 11·37 Scarifying, 0·10 x 8 = 0·80 + screening = 3·00, . 3·80 Rolling, ... 9·63 Pence, . . 32·30
5·00			

NOTE.—One ton of metalling 1 in. deep covers 32 square yards.

r Division.

'ear 1898–1899.

Haulage ı-mile, and Total ost per ton.	Width of Coating and Depth of Metalling.	Quantity of Metalling required in tons.	Price per ton consolidated.	Cost of each Section.	Total Cost.
			s. d.	£ s. d.	
·om quarry + ½ dis- long road = 2·56 at 19·84 28·50 ce, . . 48·34	18 feet wide, 4" thick.	1760 × 1·12 = 1972 × 6 = 11832 ÷ 8 = 1479	4 0⅛	298 0 4	
rom quarry + ½ dis- lividing line = 0·345 at 7¾d. = 18·17 31·58 ce, . . 49·75	14 feet wide, one stone thick.	1760 × 0·69 = 1214 × 4⅔ = 5665 ÷ 14 = 404	4 1¾	83 14 11	
·om quarry + ½ dis- ı dividing line = ·155 at 9d. = 19·40 31·58 ce, . . 50·98	14 feet wide, one stone thick.	1760 × 0·31 = 546 × 4⅔ = 2548 ÷ 14 = 182	4 3	39 3 6	
:om quarry + ½ dis- dividing line = ·305 ı at 9d. = 20·75 32·60 ce, . . 53·35	18 feet wide, 3" thick.	1760 × ·61 = 1073 × 6 = 6438 ÷ 11 = 586	4 5¼	130 0 4	
from quarry + ½ dis- ı dividing line = ·64 at 7¾d. = 18·52 32·60 ce, . . 51·12	18 feet wide, 3" thick.	1760 × 1·27 = 2235 × 6 = 13410 ÷ 11 = 1219	4 3	259 0 9	
from quarry + ½ dis- .long road = 0·50 = 7¾d. = 17·44 32·30 ce, . . 49·74	18 feet wide, 4" thick.	1760 × 1·00 = 1760 × 6 = 10560 ÷ 8 = 1320	4 1¾	273 12 6	
	Total for Division.........	from A.........		to B.........	£1088 2 4

one track, the surface of the road immediately under the line of the wheels becomes depressed, or is worn hollow. To repair a road in this condition it is only necessary to run two cuts with the scarifying machine on either side, and sprinkle some fresh metalling on the loosened portions, and with watering and rolling a hard surface is obtained.

The cost of this work, including metalling at 4s. per ton, is £7 to £10 per mile.

334. Old and New Systems of Maintenance Compared.—The different methods of performing the repairs necessary to maintain a road in good condition have been described, and the cost of carrying out the work detailed. It is now necessary to make a comparison from a financial point of view between the old system of spreading the metal in patches and forcing the wheel traffic to consolidate the macadam, and the method of coating to a full width long stretches of a road and consolidating the metalling by steam-rolling.

Three different cases, among many others, taken from the author's experience, and which are typical of what is met with in daily practice, will be given of roads under varying conditions of traffic and quality of material used for repairs.

(*a*) In the first case the road, previous to being rolled, was repaired with a very hard material over which passed a considerable amount of traffic, principally agricultural, and confined practically to a few months during the winter season. On an average, spreading the amount of traffic over the twelve months it is equal to 4200 tons per yard of width of road per annum. This road may be characterized as being situated on easy gradients with good surface and subsoil drainage; in other words, a particularly well situated road.

(*b*) In the second case, the road was repaired with macadam of a hard description previous to being rolled. It is for the most part comparatively level longitudinally, resting on a stratum of retentive clay; consequently the drainage is sluggish. The wheel traffic passing over this road is equal to 6000 tons per yard of width of road per annum, and is fairly well divided between the winter and summer months.

(*c*) The third road under review has a gentle undulating surface throughout, while the traffic over it is light and principally confined to the summer months. It was repaired with metalling of a nature varying from hard and tough to that of a highly acid composition.

Road A.—The cost of maintaining this road, carried out by patching, taking the average annual expenditure per mile over a period of ten years, was as follows:—

	£	s.	d.	
Labour, including spreading the metalling, siding, scraping, cleaning, etc., ...	£24	2	0	
Metalling (hand-broken), ...	32	1	8	
Total, ...	£56	3	8	per mile.

The period to which the cost of maintenance refers was 1880–90, since which time the cost of road metal and labour has advanced considerably, while the wheel traffic has increased to a great extent. This latter item cannot be given, from a money point of view, with any accuracy, but £5 per mile per annum might meet the case; the cost of labour has advanced 12 per cent. and that of road metal 8 per cent. The cost per mile given at p. 302, namely, £56·17, will therefore be increased to £66·38 as the figure requisite for comparison at the present time.

The annual consumption of macadam was, taking the average over a similar period, 140 cubic yards or 155 tons per mile, and the cost of metalling deposited in depôts at roadside on an average 4s. 7d. per cubic yard. The relative cost of labour and material to the combined expenditure was, therefore, 41 per cent. in the case of the former, and 59 per cent. in that of the latter.

The roadway is 18 feet wide between the sod borders, but only 15 to 16 feet of metalling constitutes the road proper.

A cubic yard of ordinary 2½-inch gauge metalling, including the small material inseparable from unscreened hand-broken macadam, will cover an area of from 27 to 31 square yards according to the proportion of small stuff to the maximum sized stones, but 29 square yards may be taken as an average. The number of square yards covered per annum was therefore 4060, which is nearly one-half of the total area of the surface on one mile of road of the width stated.

A portion of this road was repaired sixteen years ago by a continuous coat of metalling 14 feet wide, and steam-rolled. The material for carrying out the repairs was taken from the same quarry; consequently the quality in either case was practically the same. The average thickness of the coating was three inches, the quantity of metalling applied being 780 tons per mile, or five times the annual quantity previously applied on the patching system.

The cost of carrying out this work, including quarrying, breaking the macadam by machine, haulage by team labour, and consolidating the metalling by steam-rolling, amounted to £156, 14s. 3d. per mile, or nearly three times greater than the sum previously expended annually. This is at the rate of 4s. per ton of material consolidated.

1890.	Cost of coating with metal and rolling, average per mile,	£156·73
1897–8.	,, refacing where necessary, . . do. . .	42·50
1899–1900.	,, coating level portions of road and refacing remainder, ... do.	101·87
1904.	,, coating and rolling full width and length, do. .	143·37
		£444·47
Surface work up to 1909 (probable life of road)=19 years at £8·15 per mile (actual cost at present time)=		154·85
	(years) 19 ÷ .	£599·32
	Cost per mile per annum, . . .	£31·54

This stretch of road has been repaired, by coating and steam-rolling, at various times since 1890, and the foregoing figures represent the actual cost of these operations to the present time.

These figures represent the annual cost of the method of maintenance of one mile of road, or 52·5 per cent. decrease in the former expenditure. The difference in the expenditure in the years 1890 and 1904 is brought about by the lessened cost of production by using power rock drills in quarrying, and in hauling the material by steam traction.

In these figures interest on the initial outlays is not taken into account, as it is quite apparent that after four years the saving effected more than compensates for this charge.

Road B.—The annual expenditure on this road, taken as in the preceding case over a similar period, namely, ten years previous to coating and rolling, was on an average £74, 18s. 6d. per mile. The quantity of metalling applied each year was 208 cubic yards or 231 tons per mile, the price of which, laid down in depôts at the road-side, was 4s. 11d. per cubic yard. The respective figures for maintenance per mile per annum were as follows:—

	£	s.	d.
Labour, etc., ...	£24	0	0
Metalling, ...	50	18	6
Total, ...	£74	18	6

These two items, therefore, bore a proportion to the combined cost of 68 per cent. for road metal, and 32 per cent. for manual labour.

The width of the roadway varies from 15 to 18 feet, while 16 feet may be taken as representing the average width, so that with the quantity of metalling stated fully 64 per cent. of road surface was coated each year.

As in the former case, the cost of maintenance if carried out at the present time would, allowing for the increase of wages and cost of metal, amount to £88·12 per mile per annum.

This road has been repaired by coating and rolling at different times since the year 1892. The average quantity of metal applied was, in the years 1892, 1900, and 1903, 1083 tons per mile; the actual cost of maintenance up to the present time being as follows:—

1892. Cost of metalling and rolling, average per mile,	£213·90
1896. ,, refacing and rolling, ,,	91·18
1900. ,, metalling and rolling, ,,	235·20
1903. ,, ,, ,, ,,	322·44
	£852·72
Surface work up to present time (1906)=14 years at £17·5 per mile=	245·00
14 years ÷ .	£1107·72
Cost per mile per annum, . . .	£79·12

This represents the comparative cost of maintenance on one mile of road, being a saving of 10 per cent. per mile per annum.

The wheel traffic on this road, about three miles in length, has increased considerably since the year 1899, and a more durable material is now used, brought from a distance of nearly seven miles, hence the greater cost of the repairs in 1903 compared with that on the previous occasions. This road requires repairing again, and the material will be brought from the same source, Quarry No. 11, p. 121. The haulage, however, will be performed by engines and wagons, and thus effect a saving on this item of expenditure of £53 per mile of road repaired.

Road C.—In the third case referred to, the wheel traffic was of a light description and principally confined to the touring months in summer; the annual consumption of metalling, which was of a good quality, being on an average for a similar period as in the preceding cases, 35 cubic yards or 39 tons per mile per annum, while the actual expenditure on maintenance for a like distance and time was £13, 15s. 6d.

The proportion of the material and labour to the combined cost was 51 per cent. for the former and 49 per cent. for the latter, the price of the macadam being 4s. per cubic yard deposited in depôts at the road-side.

The cost of maintenance by the patching system detailed above would at the present time be £23·25 per mile per annum. This line of road, over ten miles long, was coated with metalling and rolled sixteen years ago. The surface has been repaired and rolled at various points during that period; the whole length being repaired a second time, and portions a third time. The total cost up to the present is as follows:—

1890.	Cost of metalling and rolling, average per mile,	£62·00
1895.	,, ,, (portions only),	78·35
1900.	,, ,, average per mile,	55·25
1905.	,, ,, (portions only),	145·40
		£341·00
	Surface work up to 1908 (probable time for further repairs) = 18 years at £4·5 per mile = . . .	81·00
	(years) 18 ÷ .	£422·00
	Cost per mile per annum, . . .	£23·44

This does not show any reduction in the cost of the annual maintenance by steam-rolling, as greater quantities of metal have been applied and the bermes or water tables 'filled up' to widen and strengthen the road. The traffic in this stretch of highway has increased, during the last ten years, very considerably, especially motor-car traffic, consequently the proportionate expenditure on this account cannot be given with any degree of accuracy. The indirect saving to those using this road must be considerable; while mud and dust being reduced to a minimum, greater comfort is experienced by travellers compared with the former conditions.

This road forms a part of one of the leading routes for motor-car traffic through Fifeshire. Even in this case a sufficient plea is provided for carrying out rolling operations even when the annual consumption of materials for repairs, by the old or patching system, only amounts to 35 cubic yards per mile of road.

335. Conclusions arrived at from the preceding Comparisons.—From the particulars stated in the preceding paragraphs, referring to the cost of repairs on existing roads under different conditions, it is evident that maintaining them on the principles advocated, namely, obtaining the materials and performing the work by the use of modern mechanical appliances, spreading the metalling in continuous coatings and steam-rolling, provides a road not only uniform and smooth, but one which is equally good and serviceable at all times. The comparative absence of loose stones, dust in dry weather, and mud after a fall of rain, greatly reduces the tractive efforts required by horses hauling loads, and these conditions are of considerable moment to all who have occasion to use the highways. The economy of the methods of working enumerated in the preceding chapters (the results of which have been pointed out in detail) are, the author considers, conclusive, even on roads where the necessary annual outlay or the quantity of metalling used on the patching system is relatively small. The method of consolidating the road-stones described in the preceding pages is now that generally adopted, although in many instances the old system of compelling the wheel traffic to run in the patches of metal still exists. Continuous coatings the full width of the road are desirous, which, apart from other considerations, tend to effective and economical maintenance, providing the work is carried out in a proper manner and thoroughly consolidated by rolling. Fig. 127 illustrates Aveling & Porter's most recent design of their 15-ton compound road-roller.

The difference in first cost, compared with the ultimate economy and success of the work, by using a suitable class of material, compared with that of employing an inferior class of stones obtained locally, warrants most careful consideration. Experience has proved that the cheapest material is not always to be recommended, as quality, although generally involving greater cost by reason of the longer haulage, is of more importance; and the ultimate durability and economy of maintenance may be secured by employing only the best material which can be procured.

336. Surfacing Roads.—The manual labour in connection with the maintenance of the surface of a road consists of scraping the surface during wet weather, siding, cleaning side and outlet channels, repairing footpaths, etc., the labour connected with which is augmented when the material for repairs is spread in patches to be consolidated by the wheel traffic, and gathering loose stones during dry weather.

The cost of these two latter items amounts to, on an average, 1s. 3d. per

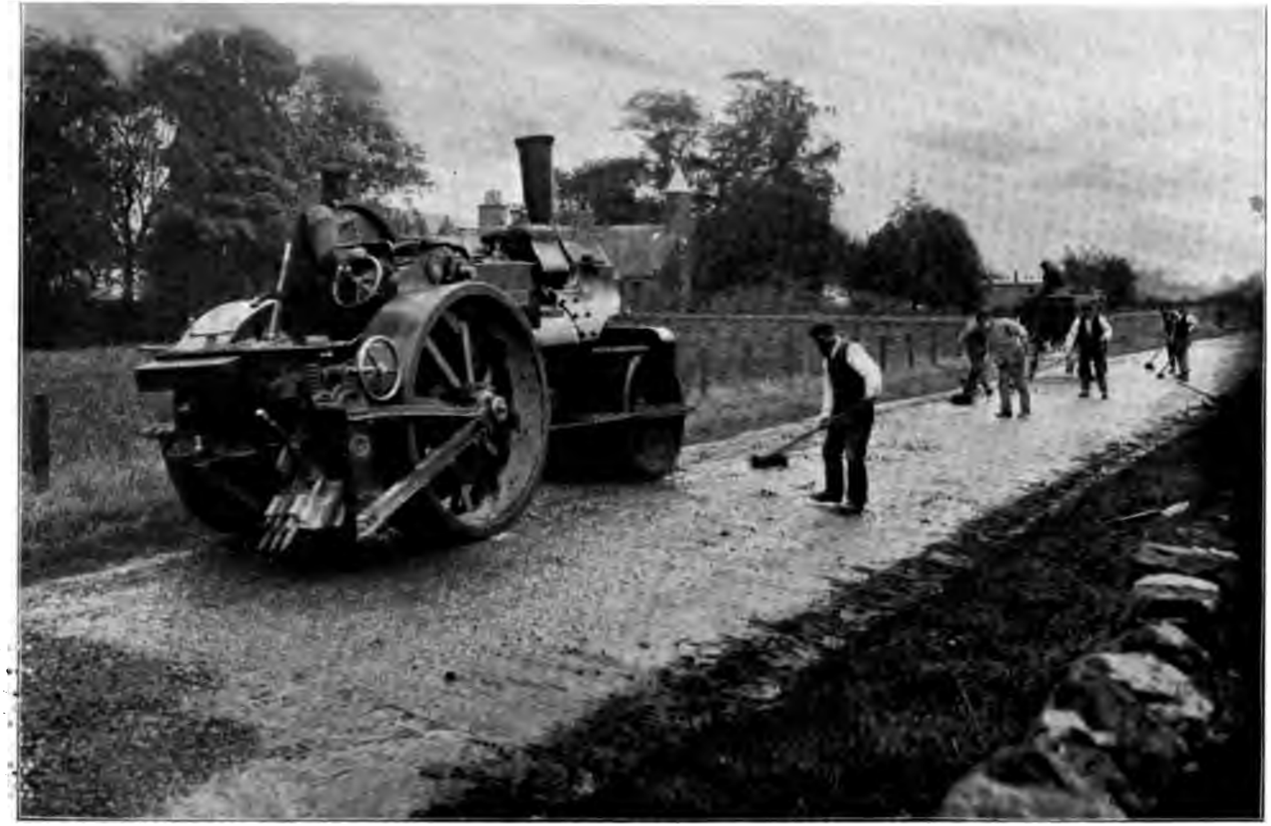

FIG. 127.—Fifteen-ton compound road-roller (Aveling & Porter's) working on road. [*To face p.* 306.

cubic yard in cases where over 50 cubic yards are applied per mile per annum; to 1s. 6d. when the average quantity is under that stated. These figures are, however, at times considerably augmented under abnormal conditions of weather and other causes.

The annual cost of manual labour per mile, allowing for increase in cost of labour since 1890, in the three instances already detailed, previous to the roads being repaired by continuous coatings of metal and steam-rolled and the subsequent actual expenditure for surface work, may be here tabulated.

TABLE XXXVII.

Road *A*	(1)	Manual labour or surface work when the road was repaired by applying metal patches, ...	£27·0
„ „	(2)	Do. do. subsequent to the road being repaired by continuous coatings of metal and steam-rolled, ...	8·15
		Difference, ...	£18·85
Road *B*	(1)	Do. do.	£27·0
„ „	(2)	Do. do.	17·5
		Difference, ...	£9·5
Road *C*	(1)	Do. do.	£6·92
„ „	(2)	Do. do.	5·50
		Difference, ...	£1·42

The difference in cost for surface work on these roads amounts to about 50 per cent., which represents a saving in the subsequent maintenance in favour of rolled roads.

From the foregoing figures, taken from actual practice, it is obvious that the greater the quantity of material necessarily employed to maintain a road in a satisfactory condition, or, in other words, where the exigencies of the traffic demand a large quantity of metalling, the process of rolling compared with traffic-consolidated roads clearly shows most decided economical results. The indirect saving must also amount to a considerable sum in each year in the reduced wear and tear caused to horses, vehicles, and harness.

337. Tar Macadamizing or Tarring Roads.—One of the most pressing questions at the present time is the change which it is absolutely necessary to adopt in the making of macadamized roads in order to suit the altered conditions of the traffic passing over them. The advent of steam rolling and the application of the best wear-resisting materials in repairing roads were an advance on previous methods of incalculable benefit to all users of the highways. In recent years a more extended use of the roads has been made in this country; and the employment of traction engines with wagons and heavy motor vehicles for conveying produce and merchandise, and also the greater use of fast-travelling motor cars, demand that some means be adopted for protecting and improving the road surfaces, thus making them more resistant against the greater amount of wear created by the increasing new form of traffic. There can be no doubt that in a great many instances formerly, inferior road materials, procured from local sources, were used, which gave bad results and were generally pronounced in mud and dust-producing proclivities.

By using such materials for repairing roads, it is not to be wondered at that the increasing and the new forms of traffic have made demands on those responsible for road management for improved conditions. Even in districts where the necessity of employing the best materials obtainable and of practising approved methods of construction were not only anticipated, but actually carried out in view of such altered conditions becoming general, the results have been entirely satisfactory; nevertheless, further improvement is necessary. In the first edition of this work it was mentioned that in view of motor-car traffic some alteration or improvement in the binding used would be imperative, in order to maintain the surface of the roads in an efficient state. It is evident, however, that notwithstanding the application of the most suitable road-stones and the employment of a binding, varying from loamy-sand to the more clayey description of material, the finished road, under abnormal weather conditions, suffers considerably, owing to the cohesion or cementitious qualities of the added material being non-efficient. Even in a normal state, under the altered and varying conditions of traffic, ordinary binding material is not as satisfactory as could be desired, and, sooner or later, the internal abrasion of the road-stone coating takes place, destroying the angles of the metal. The normal conditions under which the wear of a macadamized road presented itself formerly, in regard to traffic, were such that the disturbing element generally did not exist to the same extent compared with the conditions which obtain at the present time.

The altered circumstances, therefore, must be studied from the point of view that the surface of macadamized roads must be made to withstand the weights now permitted upon them, and the effects produced by high-speed motor cars under varying climatic conditions. Tar-macadam has been laid as a pavement in many towns—in Nottingham for as long as forty years; but the cost would appear to make its application to county roads on a large scale prohibitive.

Many proposals have been made, while road engineers have, for many years past, been endeavouring by various methods to achieve the end in view, a matter of paramount importance. The most successful system is the method of tarring furnace slag, introduced by E. P. Hooley, and known as Tar-Mac. The process of preparing this road material, as in most cases of tar-macadam, is to thoroughly dry the stones by heating, and then applying hot tar and mixing thoroughly. It is essential that all dampness be expelled from the road-stones to be used, by artificial heating on iron plates, care being exercised not to push this too far, otherwise the material may become calcined, and consequently be of little use in resisting-properties for road work.

Limestone has hitherto been extensively used and selected for tar-macadam presumably on account of its absorbent properties, while recently, dense blast-furnace slag of the best quality, a harder and comparatively better wearing material for similar reasons, has been adopted. Limestones are more or less absorbent, and the oil in tar may find its way into the pores of the stone; but it is doubtful if the tough, binding properties of tar penetrate either limestone or slag unless they are of a soft or spongy nature, and these conditions are inconsistent with good wearing qualities. In the same manner igneous rocks, especially dolerites, the constituent minerals of which are decomposed, absorb the naphtha contained in tar. In road materials of a close-grained texture little or no penetration can possibly take place; surface adhesion only can be relied on, and those road-stones which break with a rough fracture are preferable for tar-macadamizing purposes.

The heating of the stones and the subsequent labour entailed in preparing and storing the materials, although the mixing operations are now carried out by machinery, involve considerable expenditure before the treated stones can be spread on a road and consolidated by rolling. Tar-mac has been extensively used in populous places and is giving satisfactory results, even on roads subjected to considerable traffic, including omnibuses and traction engines. Although the first cost of this prepared material is comparatively high, its increased durability over ordinary macadam compensates to a certain extent for this, while a road so constructed presents a hard and smooth surface which is practically impervious.*

Other means of attaining this object, or tar-macadamizing, may be accomplished by applying hot tar to the metalling after it has been spread on the road. This is carried out by pouring the tar from buckets, or by hand-sprinkling; the object being to grout the road-stones after the coating is partially rolled, and finishing the surface by spreading dust or rock chippings over it to prevent the tar adhering to the wheels of vehicles. Undoubtedly, this is a step in advance in treating macadamized roads; but the inherent difficulty of this method is to obtain a uniform application, and of preventing a large quantity of tar, which is very mobile when in a hot condition, reaching the bottom of the metal coating. Such irregular applications will sooner or later affect the work, and the tar will become sticky and troublesome in hot weather, and probably bring about disintegration.

The application of boiling tar on cold road-stones also deserves consideration, as in many cases it will be found that the tar is chilled, which condition renders it liable to peel off the stones. A system of top-dressing macadamized roads after being consolidated in the ordinary way is practised in the Highland district of Perthshire. This is carried out after the road is dry, and consists of the small chips or screenings from the stone-breaker, previously treated with tar, being spread over the surface and rolled, and has given, so far, fairly good results.

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* The principles which govern the manufacture of tar-mac are similar to those which are kept in view in the latest methods of tarring roads, which have as their object the penetration of the surface, and the binding of the parts together to form an impermeable surface.

These methods of treating macadamized roads with tar have been practised for years past in Canada and Australia, and also in the U.S.A.

The great difficulty hitherto experienced has been the application of the tar. Being of a viscous nature, it is impossible to use it in a cold state with ordinary appliances. A heating apparatus is, therefore, necessary for its application, either when treating the road-stones for subsequent use or for *in situ* work. This necessarily involves considerable expenditure, and augments the cost per ton of metal applied.

It is absolutely necessary that the tar should be matured or refined before using, as the light oils and ammoniacal liquor are deleterious elements. It is also essential that the tar should contain a sufficient amount of binding or viscous ingredients, which otherwise would be deficient in toughness. Tar varies very much in quality at different gasworks where it is produced, and even to a great extent at the same works. Good and poor qualities of tar are apparently quite common, and chemical analysis, so far, has not been able to differentiate between them. Undoubtedly, very good results have been obtained on many tar-macadam roads, while work of a similar nature has sometimes proved far from successful. The nature of the road-stone may to a certain extent account for this, but it is the general experience that the quality of the tar demands careful consideration. Certain varieties of rock used as road-stones, although very successful under ordinary circumstances, do not, from their mineralogical aggregation, satisfy the conditions for tar-macadamizing. Road-stones, especially of the dolerite variety of rocks, which possess a rough fracture, and which have been more or less discarded in favour of better wear-resisting material, are, owing to this peculiarity, better adapted to retain the tar coating. These descriptions of road-stones bind better and form a homogeneous mass, and, therefore, eliminate internal wear of the metal coating. On the other hand, road-stones composed of large crystals of quartz cannot reasonably be expected to prove successful materials when treated with tar.

The application of tar to macadamized roads has occupied the author's attention for many years, and various methods of applying it have been tried with, generally speaking, beneficial results, but in a manner and at a cost which would not warrant its general introduction. Further consideration of the matter showed that if tar could be applied in the form of a fine spray in re-coating operations, the object aimed at would be attained. By such means, the ordinary method of applying water and some form of earthy binding material would be dispensed with and a practically waterproof road formed which would reduce mud and dust to a minimum. The results of these experiments, favourable in most particulars, led the author to devise an apparatus for spraying tar, either in a hot or cold state, into the newly spread coating and so act as a matrix or binder instead of using water and a binding material. This apparatus has been in operation for some considerable time, and satisfies the necessary requirements.

The principle on which the apparatus works is pneumatic, by which means, tar in a cold state can be sprayed in a highly diffused form and in varying quantities according to requirements. This pneumatic tar-spraying apparatus can be fitted on to existing water-carts or vans, as shown in figs. 128 and 129, a description of the details being given in a footnote accompanying the diagrams.

In operating this apparatus it is necessary, in the first place, to pump air into the receiver to a pressure of from 100 to 150 lbs. per square inch, depending on the viscosity of the tar, before forcing the tar into it from the tank. In order to obtain this pressure it is necessary to travel the vehicle for some time along the road, or it may be accomplished by lifting the wheels clear of the ground and attaching a driving belt to a road-roller or traction engine. Once the necessary pressure is attained it remains constant, and the machine is at all times ready for working, and when the desired pressure is registered the valve is adjusted so as to pump in tar, or tar and air, from the tank into the receiver. When the latter is about half-filled with tar the pressure will rise to from 200 to 250 lbs. per square inch, when the apparatus is ready for spraying the tar. The outlet valve may be regulated to give an exceedingly fine spray, or a larger quantity may be applied by opening it to three-quarters or full cock. The supply-regulating valve must be so adjusted that the quantity of tar pumped into the receiver will equal the amount of tar being sprayed on to the road. The metalling is not rolled, in the first instance, as in the ordinary system of consolidating the material, the object being to cover all the surfaces of the road-stone with a film of tar previous to consolidation. This is carried out by passing the spraying machine over the loose metal once in either direction, which, combined with the great pressure exerted in forcing the tar through fine spraying nipples, ensures the whole mass of stones, to a depth varying from 3 to 5 inches, being equally treated. The fineness of the spray secures equal distribution, and the pressure forces it well into the metal coating.

After a length of from 30 to 50 yards, of full-width coating, has been sprayed with tar, a light layer of small chips is applied to assist in filling the interstices, especially at the surface. The author, in using 2- to 2½-inch gauge road-stone, finds this necessary to make a solid and homogeneous mass. With road-stones of a smaller size—1-inch gauge, for instance—the

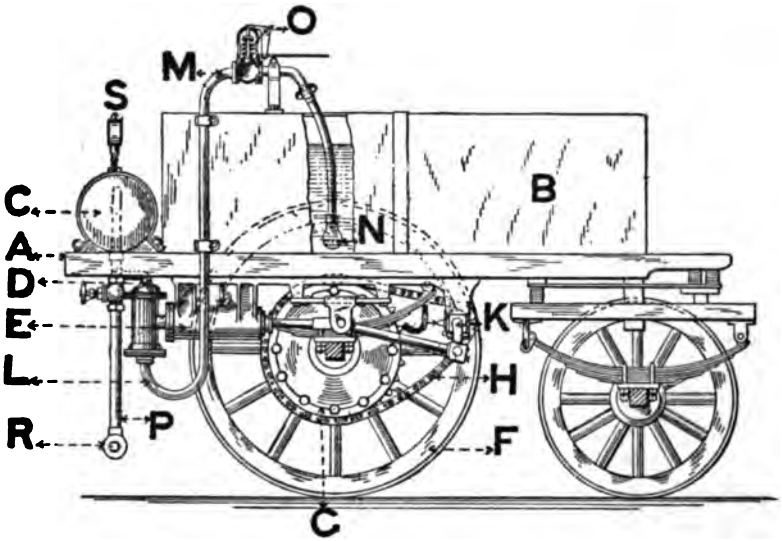

FIG. 128.

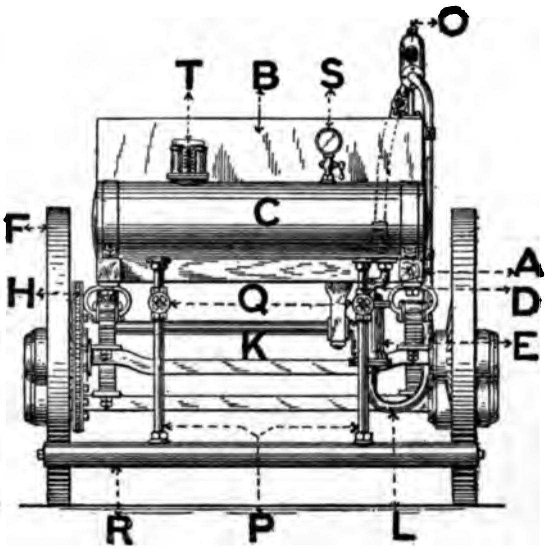

FIG. 129.

AITKEN'S PATENT PNEUMATIC SPRAYING MACHINE.

Mounted on the frame A on the vehicle is a supply tank B, to contain the tar or dressing liquid. A receiver C, for liquid and air under pressure, is placed at the back of the tank and is connected by an inlet pipe D with an auxiliary air and liquid pump E. The pumps are operated from road-wheels F by a chain wheel G, fixed to the road wheel, which drives through a chain H to a toothed pinion J, actuating the crank-shaft K of the pumps E. The inlet L to the pump is connected with the supply tank B by a flexible metallic tube M, with strainer N at end. An air inlet and regulating valve O is provided in the pipe M, between the supply tank and the pump, so that either air or liquid may be admitted to the pump, or the proportion of liquid and additional air may be regulated as required. The liquid may also be taken from the bottom of the tank to the valve chamber. Feed pipes P, regulated by cocks Q, lead from the receiver to a distributing pipe R, provided with spraying nozzles, which discharge the tar or liquid into the road surface. The distance between the distributing pipe and the surface level of the road may, if desired, be variable to suit the varying pressure in the receiver, the condition of the road, etc. An outlet with regulating cock is provided in lower part of receiver at C, for attaching a one-inch flexible metallic tube 10 to 12 feet long, with spraying nipple at end for treating isolated pieces of road, footpaths, etc. A pressure-gauge S, safety-valve T, and a manhole are provided in the receiver C.

necessity of applying chips is not essential for efficient consolidation. The main point is to use as little tar as is consistent with proper binding and to apply chips, if necessary, so that the insterstitial vacant spaces will be filled with as much hard material as possible. When the coat of metalling has been thoroughly rolled the spraying machine traverses the road and sprays the surface, one turn generally being sufficient. A thin coating of very fine chips and dust from a stone-breaking machine is then spread uniformly over the surface and finished by further rolling. No sweeping is necessary by this method of construction, therefore a considerable saving is effected in labour and the cost of brooms. Two or three men only, according to the conditions of the work, are required to rake into position or add more metal and apply the chips when necessary.

There is seldom any necessity for applying fresh material during rolling operations to make up depressions, experienced in the ordinary method of working through the old surface being softened by watering and the displacing action caused by the brooms in sweeping over the road-stones.

The amount of tar necessary to properly coat the road-stones for every ton of metal applied, varies according to the size of the material used and the quality of the tar, but from 4 to 6 gallons may be considered sufficient under ordinary circumstances. This quantity of tar would, therefore, with a 3½-inch coat of metal, be equal to 0·56 of a gallon per square yard of road covered.

The initial cost of making roads by this system is greater than by the ordinary method. The material after consolidation, however, becomes a homogeneous mass, and internal friction or abrasion is eliminated. The prolongation of the durability of a road so made will be greater, probably doubled, compared with the ordinary method of construction, consequently ultimate economy will be promoted. The surface of a tarred road is practically waterproof, and the elimination of dust and mud, or their reduction to a minimum, would alone be sufficient to justify the general application of tarred-macadam.

The cost per day of carrying out the work in the manner described for consolidating 130 tons of metal each day is as follows:—

TABLE XXXVIII.

	£	s.	d.
Engineman,	0	4	0
One man, at	0	4	2
Two men at 3s. 6d.,	0	7	8
Tar, 5 gallons per ton = 650 gallons at 2d.,	5	8	4
Two horses for tar tanks, 8s.,	0	16	0
Coals, oil, etc.,	0	2	9
Depreciation, etc., on engine carts,	0	3	6
130 tons ÷	£7	5	9

13·46 pence per ton.

It will be observed that the hire of two horses is charged for, but in most instances one horse only is required. The cost of spreading the road-stones and chips being the same in either case, it is unnecessary to take these items into account in making a comparison. On referring to p. 242 it will be seen that the cost of consolidating the metal by the ordinary methods is 7·63d. per ton, or about 6d. less than when tar is used. The cost of tarring and rolling a 3½-inch coat of metal is, therefore, 1·5d. per square yard. On a road 16 feet in width, the additional cost by using tar would be £26·08 per mile over the ordinary method when water is obtained free of charge. On a similar road, but using 6 gallons of tar per ton of metal applied, instead of 5 gallons, the cost would be £35·16 per mile more than consolidating macadam in the ordinary way. The amount of water required per ton of metal, by the usual methods of consolidation, is about 40 gallons, and when this has to be paid for the cost may be taken at 2s. 3d. per day.

The cost of tar varies considerably in different localities, but the quality is of the greatest importance, and only the best distilled descriptions should be used. The best form of vehicle for spraying the tar is a motor van having a large tank capacity holding about 800 gallons, which would be more than sufficient for one day's work in rolling the road-stone coating.

The results of the method of construction or repairing roads described in the preceding paragraphs show that the road during and after the trying climatic conditions of alternating frost and thaw presents a smooth, compact surface. The 'licking up' of the road-stones by the wheels of vehicles under such conditions on ordinary macadam is very great, and considerable damage is thereby caused. On tar-macadamized roads, however, experience shows that 'licking up' does not take place under these circumstances, consequently economy is promoted by the reduced cost of maintenance.

The method of flushing the tar over the surface, or grouting, requires from 7 to 9 gallons of tar for each ton of road-stones applied. This quantity is, however, excessive, and it may become sticky and troublesome in hot weather, and may lead to the disintegration of the surface.

It is essential that the road metal, chips, and dust should be in a thoroughly dry state, as moisture militates against good work; therefore rolling operations by this process can only be undertaken in fine weather. The finished surface is like asphalt in appearance, and, while not equal to it in actual wear, has superior properties in some respects. Tar-macadamized roads have a certain amount of resilience, foothold is much better, and they are practically noiseless compared with asphalt pavements.

The reason why tarred macadam, carried out in a proper manner, is free from dust and mud and wears longer than ordinary macadam, is simply because the frictional resistance of the stones is increased to such an extent that internal motion and rubbing are prevented, and the tar and chips which fill the interstices of the metal coating prevent percolation of water and the evils resulting from that cause. This fairly represents the possibilities of this form of construction or tar-macadamizing.

338. Subsequent Labour on Rolled Roads.—The manual labour on rolled roads, that is, when considerable stretches are thus repaired at one time, is made up of trimming the sides, cleaning side channels and water tables, opening outlets, ditching, and occasionally scraping the surface off the roads during wet weather. The length of a section of a road which one foreman surfaceman, with occasional assistance, can properly look after when the roads are repaired in patches, depends on the quantity of material applied each year and the situation of the road. Where the annual consumption of metalling is from 200 to 300 cubic yards per mile, one foreman can generally attend to three miles of road, receiving assistance when spreading the macadam and in scraping the surface during inclement weather. The length of section may be increased to five or six miles when the annual consumption of materials is about 40 cubic yards per mile. On rolled roads where the repairs are carried out on the continuous coating principle, the length of the section under the charge of one foreman can be extended to six or eight miles when it is made up of portions of different roads lying in convenient proximity to each other. The foreman should be constantly employed on his section of road during the winter months and in wet weather, but during the summer months his services, not being required in most cases for surface work, may be available in connection with rolling or breaking operations. An occasional visit, especially after a rain-storm, is all that is necessary under these improved conditions in summer. The loose stones requiring to be removed from the road surface during dry weather when the repairs are carried out on the patching system, unless consolidated by the steam-roller, occupy the roadmen's time to a considerable extent. On roads which have been efficiently rolled, loose stones are the exception ; indeed, many roads require little expenditure in this respect.

339. Tools required for Surface Work.—The tools which each foreman roadman should have at his disposal are a shovel, spade, line and reel, pickaxe, barrow, and a hand-machine scraper, extra spades and shovels being necessary when casual labour is employed. The spirit-level and boning-rods formerly used by the ordinary roadmen are now employed only by the foreman in connection with the rolling operations. Even these are dispensed with when a thoroughly experienced man is in charge of the work, except in forming new water tables or channels, a good eye being in most cases a sufficient guide in carrying out the work.

A hand scraping machine should be provided on every roadman's section, and when the extent of the roads looked after by one man exceeds four or five miles, or the exigencies of the traffic and situation of the road demand it, two or more machines should be provided.

These machines, although not intended for constant use on rolled roads, supplement the work done on certain portions of them by the horse scraping and sweeping machines. On a road which is repaired on the patching system, or when the surface of a road becomes 'cupped' through irregular wear, the hand scraper is the only form of machine that can be advantageously employed.

To maintain a road in a good and hard condition it is necessary to remove the detritus resulting from the wear of the metalling. This is generally in the form of mud, although dust is sometimes removed from the roads, which, however, is only practised to a limited extent.

To be a substantial advantage the scraping of mud off the road should be done promptly when the weather is favourable for the work.

The detritus being on the surface of the road and increasing in quantity during wet weather, evaporation is prevented and considerable damage is caused to the crust of a road in the event of a sudden thaw succeeding a frost.

The weather during the winter months is generally so changeable that continuous or extensive operations with hand scraping machines are limited.

It is very desirable, not only for those making use of the roads, but also for the benefit of the road itself, that any mud formed on the surface should be immediately removed by scraping or sweeping.

The short working day inseparable from the time of the year when these operations are carried out does not admit of much work being performed, while to employ extra men specially would incur a considerable expenditure.

340. Horse Scraping and Sweeping Machines.—A long stretch of road is cleaned in the shortest possible time by employing horse scraping and sweeping machines. The former is used when the mud or detritus is in a sticky condition, while the latter is employed when the mud is in a liquid or semi-liquid state.

These machines are constructed so that the scrapers or brushes are mounted on the framework oblique to the direction in which they are drawn; they clean a track about 6 feet in width, and the mud is deposited at the sides of the road. The framework is a combination of oak and wrought iron, the shafts being made of ash, while the wheels in the case of the sweeping machine are made with iron naves, oak spokes, and ash felloes. The wheels of the scraping machines are made of wrought iron; they are 3 feet 9 inches in diameter, while those of the scraping machine are 4 feet 9 inches.

The hoes or shoes of the scraper are made of cast iron and can be easily renewed, means being provided for regulating the tension of the springs so as to give them the desired pressure on the road. The sweeping machine is provided with double clutch gearing which imparts the motion to the circular brushes. They are provided with a driver's seat, and the levers for manipulating the mechanism are within easy reach, avoiding the necessity of the man dismounting or even stopping the horse while working the machines. Oil-cups properly protected with lids are provided for lubricating the working parts.

To minimize the scraping of roads during the winter months when the working days are of short duration, it is advisable to make use of every opportunity during the autumn and the beginning of winter for scraping the surface of the roads and cleaning out water tables, side channels, and ditches.

341. Alternating frost and thaw will at times frustrate the best regulated system of maintaining roads, and it is only by exercising patience, and making use of the appliances at hand at the proper time, that the best results will be attained under these circumstances. In cases where the humidity of the atmosphere, in the absence of rain, causes the mud to become very sticky, great difficulty is experienced in removing the detritus from the roads. Under such circumstances, it is advisable, where a supply of water can be obtained, to water the surface copiously, and then commence scraping with the horse machine.

In cases where the mud, even with this treatment, remains sticky, the author has obtained good results from watering the road and working the road-roller over the surface; by which means the thick mud is converted into a semi-fluid state, and can be easily removed by the horse scraping or sweeping machine.

The road scrapings should be removed from the water tables immediately after being deposited there by the scraping or sweeping machines, or, when in a semi-liquid state, as soon as they are in a condition to be shovelled, so as to admit of the surface water draining freely into the side channels.

Scraping should not be attempted immediately after a thaw succeeding frost, as the surface of the road is then tender, and the stones are easily displaced.

342. Amount and Cost of Work which can be performed with Hand and Horse Scraping Machines.—The cost of scraping a road with a hand machine will, of course, depend greatly on the amount of detritus to be removed and its condition. When the latter is in a soft or pliable state, and from ½ to ¾ inch thick, one man can, on a road of about 5 to 6 yards wide, thoroughly scrape about one-fourth of a mile in a day, being equal to an area of 2200 square yards, or nearly half an acre.

Under the conditions stated, this is at the rate of 12s. per mile of road. The cost of performing the operation with a horse scraping machine on a similar length and width of road, including repairs and depreciation, is on an average from 3s. to 4s., according to the thickness and condition of the mud.

The length of road which can be scraped in one day of seven hours with a horse machine may be taken at three miles, where the width is such as to require from four to six passages of the scraper. The work which can be performed with a horse scraping machine is, taking the exigencies of the traffic into consideration, on an average, about 4500 square yards per hour.

The extent of surface which can be cleaned in one day with a horse sweeping machine may be taken at about 50 per cent. more than that which can be cleaned with a horse scraper, or about 4½ miles of road of an average width of 16 feet under favourable conditions.

343. First Cost of Hand and Horse Scraping Machines, and Repairs. —The first cost of a hand scraping machine of the usual type, mounted on iron wheels with steel hoes or shoes, is from £3 to £4, and the number required in country districts averages one for every three or four miles of road.

A horse scraper of the class described, and constructed by the Messrs. Wadsworth, Halifax, costs from £19 to £24. The renewals are confined principally to the hoes or shoes, which wear unequally, necessitating their position being rearranged occasionally, and practically renewed every three or four years according to the amount of work performed. A complete set of these scrapers or shoes, twenty-seven in number, costs 35s., including time for fixing them on the machine.

The cost of a horse sweeping machine varies from £30 to £35, the wearing parts being more numerous than those of a horse scraper. The bass of the revolving brushes requires renewing as it is worn out. On an average, a new set will be required after sweeping a stretch of 200 miles. The cost of refilling the brushes with the best pure Bahia bass mixed with African weed is £2, 2s. 6d., and an equal mixture of these generally gives the best wearing results.

The chain belt, bearings of brush shaft, brush shaft ends, and knuckle joints require renewing after working about 4000 hours. The cost for these renewals is about 2s. per day of nine hours.

These machines, unlike the hand scrapers, are operated in the direction of and from the centre to the sides of the road. They are used so as to work in suitable lengths along a road, the mechanism being thrown out of gear when turning; the mud is delivered at the left-hand side of the machine, and by repeated passages the whole surface is cleaned.

The author has found the machines described in the preceding paragraphs of great assistance, especially when the roads are rolled; being light they can be drawn by one horse, are durable and easily manipulated.

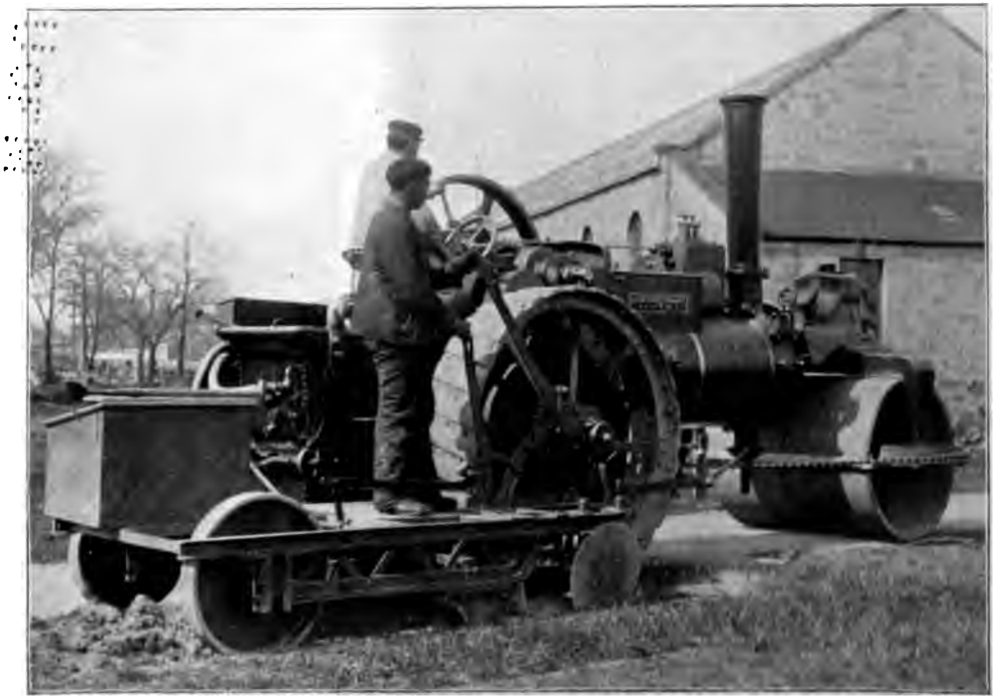

Fig. 130.—Road edge paring machine (Hogg's patent). [*To face p.* 319.

On an average one horse scraper and one horse sweeping machine are sufficient to keep the surface of 100 miles of road clean, provided they are 'stabled' centrally in the district where it is intended to use them. The work may have to be supplemented, however, by hand scraping on isolated portions of a road which are badly situated, or where hedges or close fences obstruct the sun and wind, and hinder the road from drying.

344. Road-edge Dressing Machine.—This machine, which was introduced some years ago, is the invention of the County Road Surveyor of Elgin. It is attached to a road-roller or engine, and is intended to supersede the various kinds of ploughs and other contrivances drawn by animal power, which have been devised from time to time. The machine can pare or dress the edges of public roads; the portion trimmed at one operation may vary from 6 inches to 30 inches in breadth, while it can be adjusted to cut from 1 inch to 10 inches in depth.

Besides having a suitable framework it is made up of a revolving cutting steel wheel, 2 feet in diameter, which acts in a vertical direction on the turf border to be dressed. The horizontal cutting is performed by a set of blades or cutting tools; the whole apparatus being regulated by a suitable gearing, controlled by one man operating two handles placed on the platform at the rear end of the engine. The edge-dressing machine is attached to an engine or road-roller, as shown in fig. 130, one of the driving wheels of which acts as the leading wheel of the machine, so as to give it rigidity for steering and sufficient pressure when at work. Parallel sights are fixed on the engine to guide the driver in preserving a regular course.

The loosened material is left in a continuous heap along the edge of the road and can be disposed of according to circumstances. It is a very efficient machine and does excellent work; it is capable of cutting tree roots of moderate size, rank vegetation, and of penetrating stony ground.

Under favourable conditions, this machine, attached to a six horse-power engine, can pare from 15 to 18 miles of road in one week, including the usual stoppages and changing from one part of a district to another.

It may be worked by an engine hired for the purpose, but is generally attached to a road-roller, thus utilizing the spare time should the amount of rolling be insufficient to so employ it all the year round.

The cost of paring a roadside by the machine is 8s. to 10s. per mile compared with £2 to £4 by hand labour. The price of this road-edge cutting machine fitted on to an engine or road-roller is about £90.

345. Engine and Store Shed.—In a county or district possessing a road maintenance plant, comprising roller, road-engine, stone-breaker, rock drill, sweeping and scraping machines, a shed is necessary to stable the different machines when not in use or when under repair. The shed should be commodious but not unnecessarily large, and have sufficient headway to admit of the free passage of the engines.

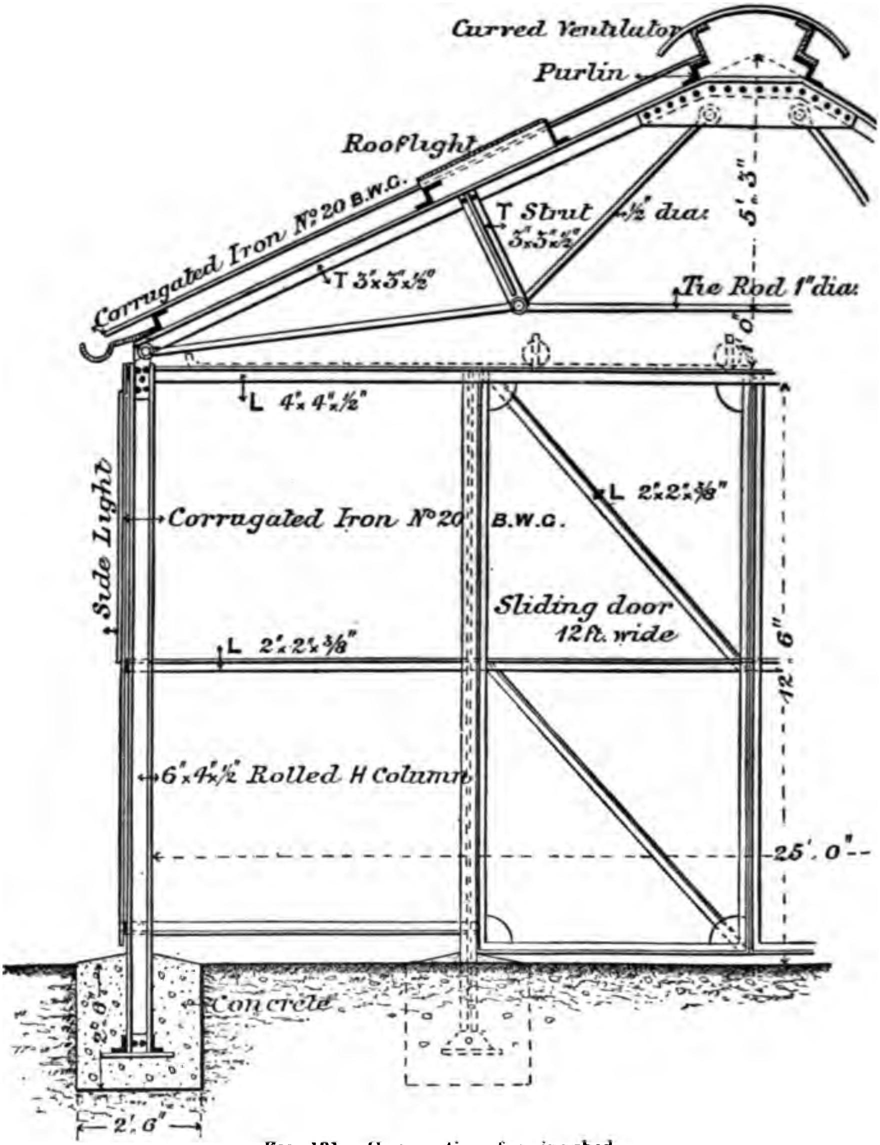

FIG. 131.—Cross-section of engine shed.

One side may be occupied by a working bench with vice, etc., for carrying out small repairs, storage for new tools, and a suitable arrangement for placing the oil casks in position. On the other side of the shed the india-rubber tubing, iron pipes, drill steels, etc., can be stored clear of the ground. A stove fixed at one end is a great convenience in many ways. It is advisable to have adjoining the shed for storing drain pipes and other material a small piece of ground, which can also be utilized for stabling the plant temporarily.

A shed to accommodate all the plant used in connection with a district extending from 100 to 200 miles of road will be best served by making it about 60 feet long and 25 feet wide; a cross-section of such a shed is shown in fig. 131.

The columns or standards are generally made of channel iron or H-section fixed at their lower ends in concrete blocks, and having the top part bolted to an angle iron run round the whole erection.

The doors, 12 feet wide, are arranged to slide by means of wheels on a T-iron fixed to the framework. The roof is made up of T-iron principals, having struts and ties, placed over the standards and fixed to the angle iron by means of a gusset-plate.

The covering is usually of corrugated iron, and of No. 20 B.W.G. fixed to angle iron runners on sides of shed, and to the T-irons of the roof principals or to purlins. The sheets should be properly lapped, and secured with bolts, washers and nuts. It is desirable to have as much light as possible admitted to the interior of the shed, and for this purpose windows are fixed either in a continuous manner, or detached, on either side of the shed to the framework. Roof-lights should also be introduced at convenient points.

A space at the apex of the principals is left open for ventilation, and a hood erected over it to prevent the ingress of rain or snow.

The appearance of the erection is greatly improved, and the corrugated iron, although galvanized, is preserved by being painted.

Cost of Erecting an Engine Shed.—The cost of erecting a shed of the dimensions given and of the materials described may vary from 1s. 6d. to 1s. 9d. per square foot of area occupied, or from £120 to £130, with an additional £5 for erecting benches and other internal fittings. It is advisable to enclose the ground occupied by erecting a fence, the cost of which is not included in the figures given.

345. In addition to having a central shed, small sheds or huts should be erected at convenient points throughout the district, for keeping those of the roadmen's tools which are not in daily use. They are also very convenient for storing coals in connection with rolling operations, as in many districts the source of supply or the railway depôts are situated at a considerable distance; in many instances they will save considerable inconvenience and loss of time.

If these huts are made of a sufficient size a considerable quantity of fuel can be stored, to supply the requirements in case of emergency. They need not be expensive erections, and may be made either of old railway sleepers or with wood posts, and covered with corrugated iron sheets, at an outlay of from £8 to £12.

346. Purchasing Tools and General Stores.—The purchasing of tools, oils, coals, blasting explosives, and detonators, demands careful attention. If the workmen's tools are obtained locally and in small lots, owing to the want of a proper place to store them, it is evident that the cost of procuring these articles is greatly increased beyond what would be that of purchasing in large quantities for one or two years' requirements. The supplying of the necessary tools and stores by contract, and delivering them at one or more convenient points in a district, tend to promote economy, and the saving effected in two or three years will be sufficient to pay for the expenditure incurred in erecting sheds and huts for this purpose.

The month of January is the most suitable and generally the most economical time to purchase tools, oils, etc.; while the contract for supplying coals for the rollers and road engines should be made in the month of March each year.

In the author's experience the saving effected by purchasing the different articles by contract annually has been 33 per cent., compared with the system formerly practised of procuring the tools and other stores as necessity arose.

347. Rules and Regulations for the Guidance of Roadmen.—Printed rules and regulations should be issued for the guidance of roadmen as to the hours of labour during the summer and winter months, the procedure to be followed in the event of a breakdown or failure of any of the subsidiary works, such as drains, culverts, bridges, embankments, etc., and the arrangements necessary to cope with a fall of snow.

These need not be of a voluminous nature, as long rules only lead to confusion, and are in most cases of little practical advantage; efficient supervision is the only way to attain the maximum results.

The regulations for the Cantonniers on the national roads in France are of a very comprehensive nature, but, apart from these, the supervision is carried out in a thoroughly systematic manner.

On roads which have been rolled, the surfaceman's work is principally confined to sliding, cleaning out channels and ditches, repairing footpaths, and occasional scraping, while his services may be requisitioned, during the summer months, in quarrying, breaking, or at rolling operations. It is not advisable to perform the work of surfacing by contract; and as the road foremen and casual labourers are paid by day's wages, the division of roads into lengths makes it easy to compare one man's work with another's when a system of close superintendence is carried out.

In districts where a fall of snow generally takes place each winter it is necessary to provide snow-ploughs to effect such a clearance as will facilitate travelling. These consist of planks fastened together in the shape of a V, 22 inches deep and shod with an angle iron on the lower edges and ¼-inch iron plates at the apex, properly stayed in the centre and outer ends, with provision in front for attaching the means for hauling it by horses. The usual size made is from 10 to 12 feet long and 8 feet wide at the extreme end. These are of little use in heavy drifts, which must be cut through by the roadmen with the assistance of extra hands when necessary.

348. **Footpaths.**—Footpaths alongside roads leading from one town or village to another are of considerable public importance, and require to be kept in an efficient state of repair. They should be formed of hard materials affording perfect drainage and finished with fine gravel, furnace cinders, or screenings from the breaking machine. In populous places it is advisable to form footpaths of a much more permanent and satisfactory nature, for which purpose tar concrete and similar suitable materials are made use of. The object to be attained is to make a perfectly dry and serviceable path during wet weather, when other parts of the roadway may be in a sloppy condition.

349. **Milestones and Direction Boards.**—Milestones indicating the distance between important towns generally exist on most of the main roads in Britain. These are now supplemented by guide or direction boards fixed to posts and placed at all important points, such as where one road branches off, or where one road intersects another. These may be made with one or more arms on which the mileage to villages and towns on either side is indicated, while in some instances the elevation of the road above sea-level is also added.

350. **Annual Estimates and Actual Expenditure of Road Repairs.**—The annual estimates of the cost of road maintenance should be made in detail, showing the allocation of the metalling, the number of cubic yards or tons per mile of road, the price per cubic yard or ton, the cost of manual labour, rolling, and any miscellaneous expenditure, such as bridge and culvert repairs, tools, etc., with the total cost on each section of road.

The actual expenditure incurred should be recorded in detail under the separate heads of metalling, road-rolling, labour, bridges, culverts and drains, tools and sundry items. This may be kept in the form of a diagram showing the cost of the different items of work carried out each year, while the total expenditure, including all these items, should be tabulated on a separate form.

It is usual to construct these 'diagram accounts' with vertical lines, on which the years are marked, horizontal lines being plotted to show the number of cubic yards of metalling applied per mile of road, the cost of this, and also the expenditure incurred for labour, rolling, repairs to bridges, culverts, and other collateral charges. These diagrams are extremely useful for reference, and the history of a road for many years, indicating its capital value, can be seen at a glance. By this means the cost of the maintenance of different roads can be readily compared, and if the system was generally adopted valuable statistics relating to roads generally would be available, so that the annual expenditure for the several items enumerated in different counties of this country could be collated, which would prove very beneficial in forming a comparison, and undoubtedly promote economy and efficiency in management.

CHAPTER IX.

THE PREVENTION OF DUST.

351. The prevention or suppression of dust on macadamized roads, generally known as the 'dust problem,' has occupied the close attention of road engineers and others within recent years, while the increasing number of vehicles travelling over the roads, especially high-speed motor cars, has brought the dust nuisance very prominently before the public generally. It is scarcely necessary to emphasize the great importance of the removal of this evil, which has manifested itself in proportion to the development of automobilism.

Its widespread effects may be recognized in the enormous amount of damage done to property by depreciating the value of houses along many of the roads used by motorists, and in the injury done to gardens and vegetation generally, articles of furniture and clothing, as well as to goods exposed for sale in shops, food-stuffs, etc. The hygienic aspect of the question is also of the utmost importance, as it is impossible in travelling along a road, or when in the immediate vicinity of motor cars, to avoid being enveloped in clouds of microbe-laden dust. In addition to this there is the inconvenience caused to pedestrians and others using the roads, and who at times are placed in imminent danger, owing to the clouds of dust raised by fast travelling vehicles obscuring the view of those following or approaching. These different conditions constitute a real danger to public health, and urgent needs exist to combat the present state of things.

Yet this dust nuisance is as old as the roads themselves. In the prime of the coaching days means were adopted for watering certain routes, but the advent of the automobile has aggravated the evil, and has directed public attention to the question of its suppression.

Now there are several factors which influence the formation of dust, the most important being the character of the road-stones employed, the binding used, and the class and amount of traffic passing over the roads. The wear of the road surface is largely due to metal-tyred vehicles, the constant wear from horses' hoofs, and, in a less degree and indirectly, to the suction and pumping action of the large rubber tyres of fast-travelling motor cars. Experience shows that a motor car travelling at from twelve to sixteen miles an hour raises no more dust than a 'four-in-hand' or an ordinary 'brake'; but as the speed increases the dust clouds become denser, and the binding and small stones are withdrawn from the metal coating. During a long continuance of dry weather and under heavy traffic the effect of the latter is such that the road is weakened and is broken up more rapidly. The resistance to traction of wheel-vehicles is greatly increased on roads covered with dust.

352. The quality of the road-stone, together with the nature and amount of binding used, are important factors, and on roads where suitable and reliable materials are properly applied and consolidated these combined conditions provide the best possible aspect of macadamized road construction. On such roads the prevalence of dust is small compared with roads constructed of and repaired by inferior materials of a softer or friable nature, such as limestones and flints.

The internal friction or rubbing together of the stones forming the crust creates dust which, in course of time, appears on the surface of the road. The binding material is a necessary factor in the construction of an ordinary macadamized road, but this during a spell of dry weather practically loses its cementitious properties and is converted into dust by wheel-traffic.

353. The design of motor cars has a great deal to do with the amount of dust raised, and this may be seen by observing cars of different types travelling along a road and the varying quantities of dust raised thereby. Experiments which have been made by the Automobile Club show that the smoother the underside of the car, with a comparatively low front and greater clearance behind, the less the quantity of dust raised. The effect of the shape of the body of the car on its dust-raising proclivities is, however, still a matter of uncertainty. Yet it can hardly be asserted that the dust nuisance would be lessened, to any great extent, by any improvement in the form of car, and therefore it is necessary to adopt other means of overcoming the difficulty. This process of dust formation increases with the traffic, and becomes unendurable on most roads where constant and fast-moving traffic prevails, and will remain in this condition until the dust is removed, either by being blown off by the wind, settled by rain, or by artificial watering, which only aggravates the evil. In the latter case mud is formed, presenting a heavy or slippery surface to travel upon, and the attendant results of side-slip with vehicles having rubber tyres.

Where the binding has been withdrawn from the metalling by the suction of the tyres of motor cars during dry weather, and the dust blown off the surface, followed by a fall of rain which may percolate through the metal coating, the foundation is damaged; and motor-car traffic is thus a means of causing inordinate damage.

354. The merits or otherwise of the rocks used as road-stones are all described in detail in Chapter IV. The climatic conditions prevailing in many parts of Scotland during the winter months cause considerable damage to the road surfaces beyond the ordinary wheel traffic, as it is a common experience to have alternating frost and thaw, rain and a muggy atmosphere, lasting for weeks at a time. Consequently, the formation of mud through wear, and the conditions just referred to, have to be carefully guarded against, as most of the material formerly in use in East Fife, containing decomposed mineral-products, produced greasy in wet and dusty roads in dry weather. Harder and more durable materials, therefore, had to be substituted, although at a greater cost; but the results were beneficial, and the expenditure for maintenance was considerably reduced. The mud and dust troubles have thus been lessened considerably, but it is difficult to contemplate what the effects of motor-car traffic would have been in dry weather if these inferior stones or dolerites had still been employed for repairs. An important consideration in the use of dust preventives is the description of material used in the roadway itself. This has been proved by the results obtained with certain preparations applied to roads constructed of different stones. It is, therefore, only by experience that it is possible to determine which composition will give the best results in general practice.

355. The different methods, in addition to the old system of watering, introduced for combating the dust evil during the last two or three years have been very numerous, but only those where practical results have been achieved are referred to.

The means of dealing with the dust evil are, therefore, as follows:—

1. Sprinkling with water.
2. Sprinkling with bituminous oils and other preparations.
3. Tarring the road surface either with hot or cold tar.

Water Sprinkling.—(1) This is the oldest, and certainly the most inefficient and injurious method, as carried out generally, of laying dust, as the water is usually applied in so copious a manner that not only is the road itself damaged, but also the dust is converted into mud, causing great annoyance to pedestrians as well as inducing the danger of side-slip in the heavier and speedier forms of traffic. To be effective, watering should be light and frequently renewed. By this means the macadam is maintained in a state of humidity, between mud and dust, and the cohesion of the material is preserved. The unceasing wheel traffic, especially of motor cars, makes water-sprinkling, during the daytime, almost an impossibility, at least in populous places. Motor water-vans, which travel at a greater speed than a horse-drawn water-cart, are now to a limited extent being employed for the purpose. It must, however, be remarked that such vans can only be economically employed where the area of roadways is extensive, otherwise the cost will largely exceed that of horse-drawn vans. Many vehicles are fitted with a special apparatus so that the sprinkling is almost in the form of a mist, or in heavier streams according to the requirements of the different kinds of roads.

The cost of ordinary sprinkling with water is generally about 4s. per mile of road eight yards wide. The number of applications varies considerably, but may be taken at about three hundred each year (2¼ times each day during the season), at a cost of about £60 per mile per annum.

Sea water has been extensively used for street watering in towns situated on the coast, the small cost being in its favour. It is more efficient than ordinary water for laying dust, but frequent applications, owing to its saline properties, produce slime in damp weather which it is necessary to wash off the surface.

Calcium chloride dissolved in water has been experimented with in various places for dust laying. In some instances it appears to have hardened the surface of a road by improving the cementitious properties of the binding. The reports on this method differ very widely, and it is impossible to give a definite opinion on the result of its application until further experience has been obtained. It may, however, be mentioned that calcium chloride, in its unrefined state, contains a large proportion of salt which has a deleterious effect on the roadway as well as on the tyres of vehicles.

356. (2) **Sprinkling with Bituminous Oils and other Preparations.**— These are for the most part palliative preparations, and therefore require frequent application in order to prevent the dust rising. One of the first of these chemical preparations to appear on the market was that known under the name of 'Westrumite.' It was originally experimented with in Germany, and was subsequently introduced into this country, where it has been fairly extensively used. 'Westrumite' is a preparation made from tar, the mineral and vegetable oils being rendered soluble in water with ammoniated soap. It is applied by means of an ordinary water-cart in varying percentages, diluted with water. Usually a 10 per cent. solution is applied first, and when the road is thoroughly dry, which takes from twelve to twenty-four hours according to the state of the weather, a second dressing, consisting of a 5 per cent. solution, is applied. These sprinklings, with additional dressings at intervals during the season, are considered sufficient to lay and hold the dust for that period. This amounts to a total application of 30 per cent. of the preparation, although greater or less quantities may be found necessary.

The estimated cost of dressing a road surface one mile in length and 24 feet wide, for the preparation alone, and taking it at 9d. per gallon, amounts to £30 per annum. The use of 'Westrumite' is said to render the surface of a road comparatively impervious, and reduces the quantity of mud; consequently the life of a road so treated will be appreciably prolonged.

'Westrumite' No. 2 is a form of soluble asphalt, and is mixed with water and applied from a special barrow by means of watering cans, or flushed over the surface with pails and brushed into the surface of the road. This preparation has been extensively used in Germany and France, and at various places in England, and, to a limited extent, in Ireland. Both these preparations, however, being soluble in water, lose their effect and are readily washed away by heavy rains.

'Pine-Oiline' is a preparation similar to the above dust-layer, but is not now on the market as a separate preparation, having become amalgamated commercially with 'Westrumite.'

'Dustroyd' is a thin, liquid preparation, insoluble in water, and is manufactured from creosote, shale, or other mineral oil, with a small proportion of coal tar, all of which are thoroughly mixed together. It dries, after application, in from three to four hours in fine weather, and is said to have good binding qualities, while an asphalt-like surface is given to the roadway which is not affected by rain. The lasting qualities are said to vary from two to three months, and three applications each year are considered effective in preventing dust in dry and mud in wet weather. The cost of 'Dustroyd' at £4 per ton is £36 per annum for one mile of road 24 feet wide, for a period of about five months and exclusive of labour. It has been chiefly used in Lancashire, and, to a limited extent, in Scotland and Ireland.

'Akonia.'—This preparation was introduced about four years ago, and has been used extensively throughout England with apparently favourable results. The first experiments made with this composition took place in Wembley and Harrow, and were so satisfactory that the surveyor of the former town has treated his roads with it through the succeeding seasons. This experience has been confirmed by a large number of surveyors in different parts of the country. The property of being odourless is in its favour, and it is claimed that it does not discolour the road. 'Akonia' is applied in a similar manner to 'Westrumite,' namely, by ordinary water-carts, and the number of dressings requisite are represented to be, practically, the same. It is claimed to be cheaper than water and cumulative in effect, so that every application adds materially to the former treatment, and goes from one season to another if the road is not disturbed. Applications of the preparation may be made every week with a weak solution, or with a stronger solution every three weeks. The price of 'Akonia' is, on an average, £2, 12s. 6d. per ton, which, of course, has to have added to it the cost of conveyance to its destination. In Wembley, as already mentioned, this dust layer was applied at intervals throughout last summer, and the inclusive cost works out at about £60 on the same length and width of road mentioned above.

'Sandisize' is a preparation consisting of an emulsion produced from wool fat and wool tar and an alkali or alkaline salt of a deliquescent nature.

'Sandisize' has been used extensively in the West of Scotland with favourable results. Being hygroscopic, it absorbs moisture from the atmosphere and practically renews its dust-arresting properties. A 5 per cent. solution applied to a road will last for two months, and an occasional shower or heavy dew improves this preparation. In Helensburgh, where 'Sandisize' is much used as a dust layer, the cost has been about £8 or £9 for one mile of road 24 feet wide for a 15 per cent. total solution sprayed in two applications per annum. The author has used this dust-laying preparation to some extent, both in re-coating operations and on made roads, the results being quite satisfactory. There was an absence of dust immediately after drying on the treated parts of the road, but in course of time the dust from adjoining portions being carried on to the former, nullified the good effects obtained. To properly test these preparations, it is necessary to treat long stretches of road at one time so as to obtain experience of the results and data as to their ultimate effect, for proper comparison. Treating one mile of road 18 feet wide with a 10 per cent. solution costs £5, and three or four applications during the season, depending on the weather, are sufficient to prevent dust rising. The selling price of 'Sandisize' is £6 per ton.

'Hahnite.'—This preparation is of recent introduction, and so far has given very good results. An experimental length of roadway was treated at Richmond, Surrey, and observation showed that it provided an absolutely dustless surface, was waterproof, and therefore unaffected by rain. It also acts as a binding agent in cementing the binding and stones together. The roadway conveys the idea of an asphaltic veneer over the macadam. This specific is said to add 33 per cent. to the life of the road, which certainly seems a very high figure.

The basis of 'Hahnite,' prepared by a special process, consists in the admixture of oil and water without saponification of the oil. The oil is laid on the road by the aid of water, the result being that the water evaporates, leaving the 'Hahnite' to penetrate the roadway without the slightest disintegration or other detrimental effects. The composition is described in the patent specification as consisting of "oil which is emulsified with carbolic acid and is mixed when heated to 150° F. with asphalt, tar, and the residue from glycerine distillation in stated proportions. The road is sprinkled with water before and after an application of a solution of the composition, preferably salt water." This forms an insoluble liquid which, when sprayed on the road by means of an ordinary water-cart, fitted with internal agitators (the cost of which is very small), oxidizes, and thereby forms an impervious coating of great durability and binding properties. At the same time it does not present a slippery surface.

There are many other preparations of a palliative description, more or less effective, but for obvious reasons it is impossible to describe them.

The palliative preparations for laying dust are of great service in towns and populous places where ordinary watering is resorted to during the summer months, and are for the most part of a disinfectant nature. The comparative cost may be stated at about 33 per cent. in favour of using the dust-allaying preparations. The cost of water and team work for each sprinkling may be taken at from 3s. 10d. to 4s. 2d. per mile of road 24 feet wide. For country roads these preparations are considered of too temporary a character to be generally adopted.

Oil.—The application of petroleum and other oils for the suppression of dust has been tried in various ways and in most countries with varying success. Crude petroleum is extensively used in the United States, especially in California and at the seaside resorts of New Jersey, instead of water. It is also largely used on railroad tracks for, as Americans term it, downing the dust.

For the most part petroleum oil has been employed on roads composed principally of gravel, limestone, and sandstone. In the first application the quantity of oil varies, as much being sprinkled over the surface as the road will absorb. The oil is applied to the road at a temperature of 200° F., the total quantity, by repeated applications, amounting to from four to six thousand gallons for each mile of road 16 to 18 feet wide. The sprinkling is carried out at different periods of the year, and generally consists of three applications in all. The second and third dressings are accomplished with a less quantity of oil than the first application. This treatment is said to reduce the amount of mud during inclement weather; but the effect of continuous rain destroys its usefulness, so that it is necessary to repeat the process each season.

The price of this dust-laying oil—which is the residuum after the naphtha, gasolene, and kerosene have been distilled from the crude petroleum, and contains about 20 per cent. of bitumen, an important constituent—varies from 4s. to 5s. per barrel (24 gallons) at the refinery.

The inclusive cost of treating a roadway one mile long and 16 feet wide works out at about £40 for the three applications, while the cost of labour and team work amounts to about £4. In San Bernardino county, California,* the actual cost of treating one and a half miles of road 16 feet wide is stated to have been £33 per mile, 120 barrels of oil being used. The cost of application, labour and team work is set down as £3 per mile.

In order to discover the best and most efficient method of treating roads with oil, the Californian Dustless Road Company conducted a series of experiments extending over two years. Their object was to find out a method by which not only dust may be laid, but how a permanent hard road bed might be obtained.

In Santa Barbara † the streets are all brought to a clean round grade. The dirt is made fairly fine, a spading harrow being used. This grading

* *Engineering Record*, 30th March 1901.

† *The Street.*

does away with holes and makes the street as even as possible before the oil is placed. Sprinkling with water follows the grading. On several blocks sprinkling was omitted to see what the effect would be. The best blocks laid are those where the sprinkling was done. The oil was heated in its car to make it run easily, and was then hauled to the streets in a sprinkling cart. This is driven slowly over the street and the oil runs out. Then comes a second coating of oil. Harrowing the third time mixes the oil well with the earth. Next comes the roller, a tamping machine which consists of a roller of wood, into which are set rods of iron spikes each a foot long, and having a head two inches square. The spikes project about six inches. The roller rolls on the end of these spikes and mashes the oil almost out of sight into the road. The treatment with this roller hardens the surface and permits the use of a heavy steam roller for the purpose of further packing and levelling the streets. The amount of oil used was 100 barrels to a 450 feet block of a 60 feet street. Traffic on the streets has hardened them into an almost asphalt surface.

Some of the streets of Baku have been oiled for twenty-five years or more, and the carriages used there have as a rule rubber tyres, which are not at all affected in the way suggested at times. Moreover, no smell arises from the roads.

Oiling macadamized roads has not been adopted to any extent in this country, which may be due to the fact already mentioned that certain descriptions of petroleum are unsuitable for the purpose, and to the mistake which has been made in not selecting the proper kind of oil for the work. Oils containing from 16 to 18 per cent. of bitumen are considered to be well adapted for this purpose. Generally speaking, the oils produced in Texas, California, Borneo, and Russia fulfil these requirements and ensure good results. They should be applied in a boiling state and when the road is thoroughly clean and dry.

Trials with Texas oil were carried out in Hampshire in 1902 on the road from Farnborough to Aldershot, three-quarters of a mile being treated. This road, in addition to carrying a large amount of ordinary vehicular traffic, is much frequented by motorists. A portion of it was repaired with Cherbourg quartzite, the remaining part being of flints, and both resting on a subsoil of sand.

The oil was applied in a cold state by means of an ordinary water-cart. Several dressings were given, which were supplemented in places by men applying the oil with watering cans to ensure, as far as practicable, an even distribution of the liquid. The road being very dry was in an absorbent condition, and the oil easily penetrated through the surface. The immediate result was that it successfully prevented the rising of dust. It was noticeable, however, that on that portion of the road previously swept the results were far more satisfactory, and so long as dry weather was experienced the road remained in a good condition; but the arrival of wet weather appears to have completely changed the fixing qualities of the oil, and the mud, compared with that on the untreated section, although the same in quantity, was of a much more objectionable character.

After the lapse of six months the oil was practically non-existent, being either scraped off the surface or washed out by the rain. The best results generally were obtained on the road which had been repaired with quartzite, while that on which flint had been used showed peculiar characteristics.

These experiments, including the oil and labour, cost about ¾d. per square yard; 11½ tons, or 2760 gallons, of oil being used. At this figure the oiling process, over one mile of road 24 feet wide, worked out at a cost of about £44. It is apparent, therefore, that whether the oil is applied hot or cold the effects of rain detract from the beneficial results obtained during the dry season. During the winter months the results of this treatment, which are satisfactory in dry weather, are destroyed, and in consequence the process has to be renewed each season. It may be concluded, therefore, that oil as a dust preventive in this country, even though the petroleum contains the proportion of bitumen mentioned, is only a temporary one.

The oiling of roads in Scotland has only been carried out to a limited extent, the trials in Renfrewshire being the only ones recorded. In this instance Scotch petroleum was used and applied, after the surface had been swept, by means of watering cans, and then brushed over the surface in order to secure, as far as possible, a uniform dressing. The oil dried in about twelve hours, and the cost of the operation was approximately £20 per mile.

357. (3) **Tarring the Surface of a Road.**—Tar has been extensively experimented with as a dust preventive during recent years, and although its use for this purpose and for the manufacture of tar macadam has been practised for a long time, its superiority as a binding medium in the construction of macadamized roads is only now being recognized. On the Continent, and especially in France and Italy, where some of the palliative preparations referred to, as well as several others, including 'Odocreol' or oil of tar, 'Rapidite,' 'Pulveranto,' have been tried, they are being superseded by the use of tar. These dust-laying preparations for the most part consist of tar with mineral and vegetable oils, emulsified or saponified in order to render them sufficiently liquid for application by ordinary methods. This process, however, appears to affect adversely the binding qualities of the tar, hence the necessity for using this product in either a natural or refined state and applying it hot.

The viscosity of ordinary tar renders it difficult to distribute evenly by the usual methods, and special appliances have been introduced into France for spreading the tar over the roads.

One of the best known of these is that invented by M. Laissailly.* This consists of a reservoir for the tar, and has a discharge pipe similar to an ordinary water-cart for distributing hot liquid on the road, and by an arrangement of brooms the tar is spread in a thin and perfectly even layer. The latter arrangement takes the place of the gang of sweepers formerly employed, reducing considerably the cost of the operation.

Dr. Guglielminetti has studied the dust problem for years past, and among other interesting items in the article referred to, the following, dealing with the hygienic aspect of the question, may be quoted:—

"The question of the suppression or lessening of dust interests, on its technical side, not only the engineer who constructs and maintains the road, but also the official who has charge of public (santé) health.

"In the exercise of our profession as doctors in various places along the Riviera, where the ravages of dust are greater, the climate is charming, the rainy days fewer and the road metal more brittle and powdery, we have, since the progress of motoring, been able to convince ourselves that there is urgent need for combating this scourge.

"The single great artery which unites the coast towns of Nice, Monte Carlo, and Mentone is the national route No. 7, and is furrowed during the winter by innumerable motors which transform the coast road into a veritable autodrome, and which, in spite of its insufficient width, is also traversed by an electric tramway. The dust here has become a real danger to public health and safety, and it is not surprising that the campaign against it should have been started in this country, and that it should have continued here with greater persistence than elsewhere."

This Laissailly road-tarring machine, which has during the past year been introduced into this country, is the improved form lately perfected and used in France.

The application of the tar by this system is by means of gravitation, but owing to the viscosity of the liquid it requires to be raised to a temperature of 200° F. The heating is accomplished by employing a separate vehicle known as the cooking apparatus, and consisting of a boiler and worm piping through which the steam passes into the tar vessel. The filling of the distributing cart is carried out by suitable means and with a minimum expenditure of time.

The hot tar passes by a pipe from the main tank into a regulating tank at the rear of the vehicle, where a float-indicating device enables it to be maintained at a constant level. By this means a uniform flow is kept up, and consequently a regular spread of tar on the road is secured. The distributing pipe, similar to that of an ordinary water-cart, permits the tar to flow in fine jets on to the road, the spreading being accomplished by four automatic smoothing brushes which ensure a thin and even layer. A binder composed of trass, Portland cement and basaltic chippings, is applied to prevent 'licking-up' and to assist in the setting of the tar, as well as for the additional purpose of improving the surface.

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* "Moyens de Combattre la poussière sur les routes," par Docteur Guglielminetti, *Le Génie Civil*, Samedi, 24 Juin 1905.

The machine is capable of spreading five tons of boiling tar, covering 2500 square yards, in an hour, and is said to do the work of fifty men by the method of flushing and sweeping formerly adopted in France.

On a perfectly uniform roadway this method of tarring roads gives satisfactory results, and is said to penetrate the material to the depth of from 1 to 3 inches, but, like hand-painting with tar on roads which are cupped or on which many surface hollows exist, the hot tar has a tendency to flow into the depressions, the result being an unequal application. When this occurs it is very apt to be worked into ridges by the wheels of vehicles, especially after rain, which is a great disadvantage in treating macadam roads. The extent of the penetration of the hot tar into the crust of a road depends on the description of the binding used and the nature of the detritus or pulverized stone filling the interstices.

The application of sand or other material dusted over a newly tarred road by the method described absorbs the tar, which must be detrimental to its efficiency. In order to obtain the best results the tar should be allowed to remain on the road as long as possible before sprinkling the surface with sand or other material.

The cost of tarring a road by this system when tar can be procured at 1½d. per gallon is stated to be 2d. per square yard for two coatings. Thus on a road 18 feet wide the cost per mile will amount to £88, and on a road 24 feet wide, £117.

Altogether, 1,200,000 square yards were treated with this machine between May and September 1906, this figure including roads situated in Worthing, Hove, Epsom, Sutton, and Shoreham.

Tar to be used in road work is generally boiled to rid it of the light oils and water before being applied. The tar produced by different works varies very much in quality, depending, in a great measure, on the description of the coal used at the gasworks, and also on the tar-extracting apparatus employed. Refined tar of the best quality only should be used in connection with road work.

The surface of the road must be thoroughly cleansed, and all dust and foreign matter swept off. In some instances it is advisable to effect this by watering the road in order to rid the surface of extraneous detritus. The road should be in a thoroughly dry state when the tar is applied, and the work carried out during fine weather only. Hitherto the application of tar has been carried out by means of watering cans, pails, and by other like methods, and under these conditions it is necessary that the tar be very hot for the purpose of manipulating it when in as liquid a condition as possible. After flushing the surface, men with brooms are employed to spread the tar equally over the surface of the road. In some instances small hand-worked spraying machines have been used for this purpose. The road when under treatment is either closed against traffic, or one half of the road at a time is tarred until it is dry and hard in order to prevent the tar adhering to the wheels of vehicles. The method generally adopted, however, is to powder the surface immediately after being treated with very fine chips and dust from a stonebreaker, sand, or other suitable material. The latter method admits of traffic passing over the surface almost immediately after being tarred.

Experimental lengths of roads treated as described have been carried out, among other places, in Buckinghamshire, Kent, Epsom, Farnham, and Leith.

358. The cost of applying tar in the manner described is stated to be from 1¼d. to 2d. per square yard, including the tar, which varies considerably in price in different localities. For the purpose of comparison, and taking the same length and width of road (one mile 24 feet wide) as in the previous instances, the cost works out from about £73 to £117. These figures appear very formidable, and such expenditure could not reasonably be expected to be undertaken by County Councils, although the life of roads would be greatly prolonged by such treatment.

As most country roads are only on an average 16 to 18 feet wide, the expenditure would amount to from £49 to £73 per mile of road respectively.

The application of tar carried out by the methods described above, unless the liquid permeates the crust of a road to a certain extent, which can only be expected in exceptional cases, is affected by the inclement and changeable weather experienced during the winter season, and will, in most instances, destroy any good results effected during the previous summer.

From a financial point of view it would not be practicable to incur the expenditure stated each year, however desirable, so far as results are concerned merely in the suppression of dust.

359. Any arrangement by which the tar, either in a hot or cold state, could be sprayed on the surface of roads will at once remove the great proportionate expenditure incurred by manual labour.

The author has been experimenting for many years past with the application of tar to macadam roads for the purpose of preventing dust, and particularly with a view to economy by increasing the life of the roads, and with this object in view he has devised the apparatus described in Chapter VIII. p. 312. The Pneumatic Tar Sprayer is shown in fig. 132 discharging tar in a cold state on a macadamized road. In this machine the double duty of rapid and economical distribution is fulfilled by reducing manual labour to a minimum. With this apparatus the tar is applied in the form of a fine mist or spray under considerable pressure and,

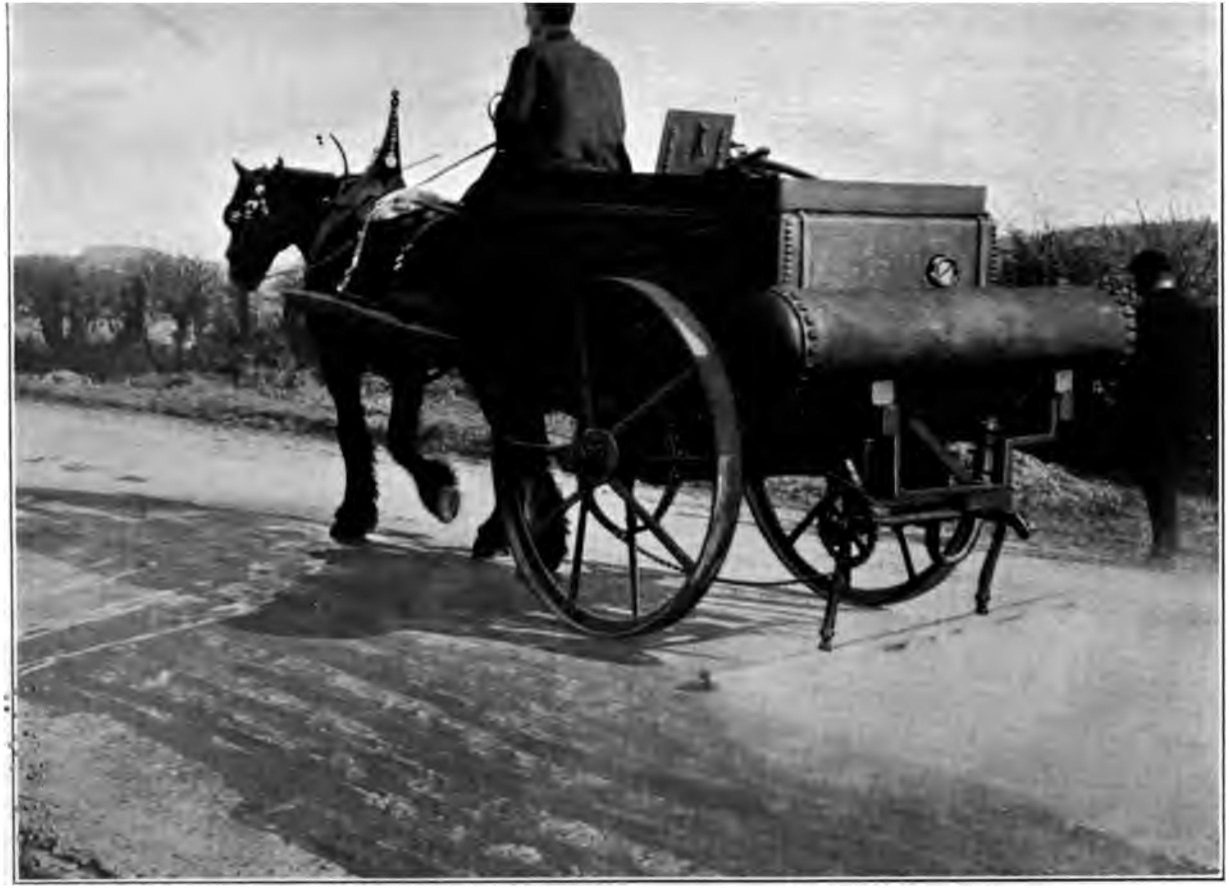

FIG. 132.—Pneumatic tar-sprayer. [*To face p.* 336.

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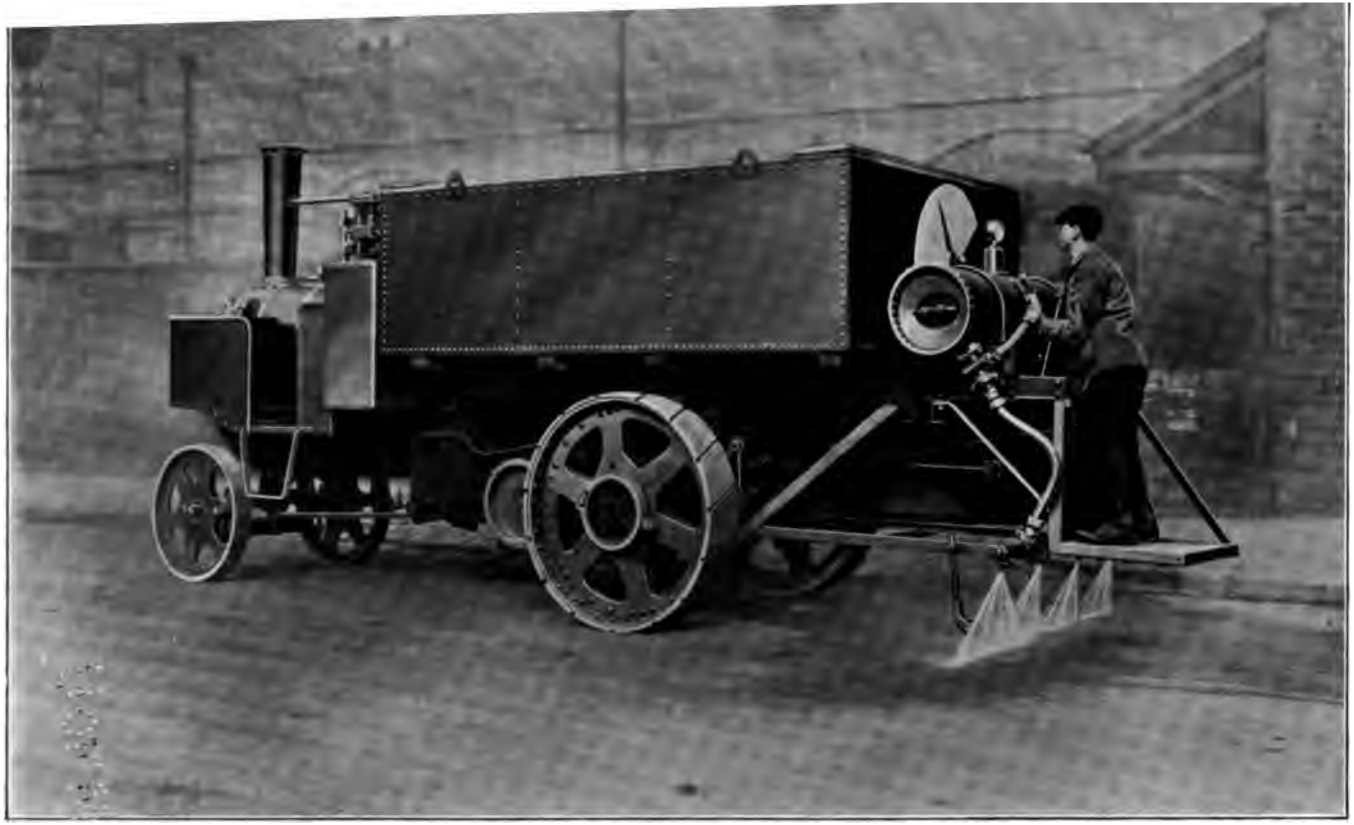

FIG. 132A.—Aitken's patent pneumatic tar-spraying apparatus, fitted to a steam wagon.

[*To face p.* 336.

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apart from assuring equal distribution, a desideratum in most methods of applying tar, forces it into the binding forming part of the road crust. The operation is simple, and no labour of brushing, either manual or machine, is required. Thus the crust of the road is impregnated and a waterproof surface is obtained.

The depth of penetration depends greatly on the clean condition of the road surface before application, and the nature and proportion of the binding originally employed when repairing the roads. When loamy-sand has been used the penetration is markedly greater than when material of a clayey description has been adopted. The actual penetration varies considerably even on roads repaired with a light description of binding, due, no doubt, to the unequal amount and density of the material at certain spots. The depth of penetration is generally 1 inch, but varies up to 3 inches. The former, however, may be considered as a fair binding medium compared with that of surface-flushing applications under similar conditions.

360. The cost of applying the tar by this method at 2d. per gallon, and including team labour, on one mile of road 18 feet wide, amounts to £11. On a road 24 feet wide the cost would be £15 per mile for one dressing, or about ¼d. per square yard, assuming the supply of tar is provided in a regular manner. If the spraying apparatus is fixed to a motor van having a large tank capacity, the cost of application would be correspondingly decreased. Dusting over or powdering the surface, preferably carried out by a sanding machine, is of course additional, but these figures are given for the comparative cost as against other methods of treating road surfaces. The cost of spraying tar will vary in different localities, depending on whether it is obtained in a crude or refined state, and on the facility with which it can be procured in sufficient quantity. The distance of the road to be treated from the source of supply and other circumstances must also be taken into account.

Portions of different roads have been treated by the method described with beneficial results, not only showing a prevention of dust in fine weather but also absence of mud after rain. It was particularly noticeable also that when a thaw with a muggy atmosphere succeeded frost, the lifting or 'licking-up' of the road-stones by the wheels of vehicles, common under such circumstances on a road repaired in the ordinary way, did not take place.

Although these methods of treating macadamized roads is a step in advance compared with the system of applying the tar by manual labour, and with the use of palliatives or temporary remedies, no real solution of the dust problem has for the time being been found, but there can be no doubt that the building up of the road-stone coating with a matrix of tar, chips, and dust as a binding medium, is the best possible method of solving the dust problem in a satisfactory and permanent manner.

361. The life of a road repaired in the ordinary way is dependent primarily on the quality of the material used and the amount of traffic passing over it, so that the intervening period of repairs varies from two to five years or longer, according to circumstances. Under these conditions the method of construction advocated would take years to accomplish, but the dressing of the surface of the roads by tar spraying, and to some extent by the palliative remedies now in use, would suppress, or at least lessen, the dust in fine and the mud in wet weather. These measures appear necessary as long as and until a more thorough system of repairing roads by the different methods described, *i.e.* by the use of tar macadam, tar-mac, or by treating the road-stones *in situ* with tar, is adopted.

Some years ago trials were made in the United States with the use of tar as a matrix, but owing to its non-success the method was discarded. Recently, however, futher tests have been carried out at Jackson, Tennessee, and were described in the *Surveyor.** The tar was applied hot, and brushed over the road surface with manual labour. The coating of sand was then spread over after the road had absorbed the tar. This absorption process varied from eight to ten hours in very hot weather, and when completed the surface was rolled. The cost of the operation, which included sweeping, tarring, dusting over the surface and rolling, amounted to nearly 2d. per square yard. Treating the surface with oil was also tried, but the results were not so successful.

362. 'Taafalt.'—This preparation, unlike some of those already mentioned, is, in a measure, of an enduring nature, and is mainly composed of tar or pitch, powdered limestone, granite, or furnace slag and an alkaline solution. These are mixed in their proper proportions, and heated to over 300° in a vacuum. When the amalgamation is complete, through chemical changes, the material is poured into moulds and is thus formed into blocks and then stored ready for use. As an alternative the material may be treated at the road side and applied direct to the surface.

It may be used on an existing road the surface of which is fairly uniform, with the addition of limestone chippings rolled into the composition before it sets hard. The preparation may also be employed when repairing roads with metal coatings by spreading it over the surface about half an inch thick. Being a surface application, the useful effects will last until worn down to the road metalling.

'Taafalt' has been laid at various places, among which is the promenade between Westcliffe-on-Sea and Leigh-on-Sea, where it is subjected to conditions of an exceptional character. It is claimed for 'Taafalt' that it is "dustless, durable, resilient, and non-skidding." It affords good foothold for horses, is waterproof, and is unaffected by climatic changes.

With this preparation there is no wear of the road proper, the 'Taafalt' doing duty as the wearing medium. With heavy traction engine traffic it is doubtful whether a composition the wearing constituents of which are such material as limestone chippings and small slag would have a very long life.

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* 16th November 1906.

The cost of the preparation laid on a road amounts to 4d. per square yard. On a road 18 feet wide an expenditure of £176 would be incurred, and on one 24 feet wide it would amount to £235 per mile.

363. Another method of making an asphalt-like surface is carried out by using chippings well coated with tar, which acts as a flux or binder in repairing roads by re-coating. A layer of the prepared composition is placed on the old surface, over which the metalling is spread and then rolled. The plastic composition is forced into the interstices of the road-stones during the process of rolling, the result being in appearance a satisfactory piece of work. The road presents a homogeneous and uniform surface, and the amount of rolling necessary is less than that required under the ordinary method of using water and earthy binding. To some extent the cost of rolling is reduced, but the additional expenditure involved in spreading the road metal under these conditions does not lessen the total cost materially. Besides this, the author has found that the matrix composition, owing to its density, gives an undue proportion of small matter compared with hard wearing material, and, in addition, too much tar is incorporated in the crust of a road thus made. The result is that an irregular surface is formed by wheel traffic under varying climatic conditions.

Whinstone chippings similarly treated have been used in a thin layer as a top dressing on macadamized roads with good results so long as fine weather is experienced. The composition, however, cannot be properly amalgamated with the metalling, and has a tendency to peel off the surface of the road during wet weather, and especially after the prevalence of frost. The cost of this method, as carried out in the Highland district of Perthshire, amounts to about ½d. per square yard.

364. Oil-gas tar has also been fairly extensively used for the prevention of dust, and the results are said to have been satisfactory. Being more fluid than ordinary tar, it is easily distributed by means of water-carts, not possessing the same body as coal-tar. This, however, makes it necessary to increase the number of applications during the season in order to secure effective results. The cost of using this material is said to work out at about £14 per mile for each application.

In the experiments carried out at Tunbridge Wells* an oil was used which is a by-product in the manufacture of coal gas, enriched with carburetted water-gas. The oil used for this enriching process is known in the trade as solar oil, which is a by-product, previously a waste product, in the refining of Russian oil. Russian crude oil is a heavy oil, and yields very different products from the Pennsylvanian oil, which possesses a paraffin base. It is found that the oil-gas tar, as it is called, obtained from the gasworks, gives very satisfactory results when applied to roadways.

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* Report by Mr. Maxwell, *The Street*, 28th July 1906.

The method adopted in laying down this oil is as follows:—

The preliminary making good of the roadway surfaces; the thorough sweeping off of loose dust and horse droppings; the preparation and heating of the oil-gas tar at the site in a suitable 50-gallon cauldron; the application of the liquid, in its hottest condition, to the well-cleaned road surface by means of hand water cans with coarse rose or spreader, or from a small hand water-cart, which is preferable to the use of an ordinary horse water-cart, as the smaller bulk of liquid facilitates its application in the hottest condition, and, too, hand distribution is found more flexible in working with the traffic, which need not be stopped; and the brushing of the liquid into the surface with fairly stiff-haired tar-brushes. The number of coatings was repeated until the pores of the road surface showed signs of being well filled, and a close asphalt-like face obtained.

The advantages of the treatment experienced were: The oil-gas tar could be applied to the road without stopping the traffic, and the liquid sunk rapidly into the road crust so that vehicles were able to pass over the site without inconvenience almost immediately; there was no tendency to 'lick up' at any time either when freshly put down or after rain. The closing of the road, diversion of traffic, licking up, and working into ridges caused by the traffic, are important practical disadvantages in the use of ordinary gas tar (applied by hand) not present in the case of the oil-gas tar as used at Tunbridge Wells; the application can be much more expeditiously done than is the case with coal-gas tar, and the cost was found to be very much less, owing to the lower price of the oil-gas tar and reduction of labour in its application. The first coat, including preparation and sweeping of the roadway surface, cost about a halfpenny per square yard, while each succeeding coat cost less, owing to the greater area covered per hour and per gallon of liquid; the surface was not adversely affected by rain, and the treatment remained in good condition from May till the end of October on surfaces lying fairly level, and much longer on roads having a small incline sufficient to keep them well drained; the protective asphalt-like skin which quickly formed under the run of traffic over the surface of the road effectually prevented dust and materially reduced wear and attrition of the road metalling surfaces.

365. As has already been mentioned, the quality of distilled tar is an important factor in spraying road surfaces. If the distillation be pushed too far or pitch added to an excessive degree, the tar will become brittle after setting, and liable to be crushed into a form of powder by wheel traffic, which is most destructive and worse than ordinary road dust. On the other hand, if it is insufficiently boiled, then the volatile oils which remain

will be adversely affected by the atmosphere, and possibly cause disintegration. The application of boiling tar to a cold road surface, especially if the road-stones are fully exposed, or should the metalling be chiefly composed of large crystals of quartz, has a tendency to become chilled on the surfaces of the stones, and consequently the tar will not adhere to them, which adversely affects the dressing on the advent of rain, and particularly during the winter months.

Too much tar on the surface of a road, a common experience with hand-painting and sweeping, is more objectionable than the evil which its application is intended to cure. It may present a fairly satisfactory surface under normal weather conditions, but during hot weather it is easily indented and has a ribbed and irregular appearance, while in wet weather the extraneous tar is invariably converted into greasy, slimy mud.

In fact, tar painting or spraying is useless unless there is an effective penetration of the surface of the road, and undoubtedly the pneumatic tar sprayer has proved itself to be a most efficacious, economical and expeditious apparatus in accomplishing the end in view as well as in preserving the cohesion of the crust of the road, which becomes of a durable nature.

Tar spraying for the prevention of dust, and, to a certain extent, to assist in prolonging the durability of the roads, may now become more widely adopted by the use of this mechanical apparatus. Tar treatment, hitherto carried out chiefly by manual labour, was an expensive luxury by reason of the crude process of application. Now, however, it can be executed in much less time and at a fraction of the cost formerly necessary.

Tarring roads is the cheapest form of dust prevention, providing the tar is distilled and of good quality and properly applied. A road so treated combines many of the advantages of asphalt, with perfect freedom from dust and increased durability, owing to its practically waterproof character. It is a more effective and durable method than any of the preparations previously tried, and affords a good foothold for horses, is comparatively noiseless, while it lessens the cost of scavenging.

The life of tarred roads efficiently carried out is still an open question, and time will be required to determine their value in this respect, though from the experience already gained it would not be too much to expect that the life of a road properly treated would be doubled.

PART II.

CHAPTER X.

CARRIAGEWAYS AND FOOTWAYS.

PRELIMINARY REMARKS—FOUNDATIONS AND PITCHED PAVEMENTS.

366. The method of paving streets and carriageways, which forms Part II. of this treatise, will now be described, beginning with the earlier kinds of material used, such as cobblestones, and finishing with what is now employed in the large cities and towns of this country.

The historical part of this subject, as also the methods adopted in obtaining many of the kinds of material used for paving purposes, but especially in connection with the construction and repairs of macadamized roads by steam-rolling, have been fully explained in the different chapters in Part I. Such matters, therefore, will only be alluded to in the following pages as are necessary to further elucidate or amplify the subject.

Stone in many different forms has been made use of as a paving material from the time of the Romans, who employed blocks of an irregular shape laid on a foundation of concrete, which presented great solidity and was extremely durable.

The surface of these large blocks having few and irregular joints, however, does not afford a good foothold for horses, owing to its wearing smooth; consequently this form of paving is not suitable for modern traffic.

Boulder or cobblestone pavements were much used in the towns of this country until they were superseded by regular pitched paving. Cobbles make a very noisy pavement, and from the irregular shape of the stones it is impossible to joint them closely. The surface, therefore, cannot be properly cleansed, and consequently they form an unsuitable as well as an insanitary paving material. Streets in many of the English towns are still paved with cobbles, but these are being gradually replaced by better descriptions of pavement.

The large regular-shaped blocks, 8 inches wide, introduced in more recent years, have been gradually reduced in size, the width of the setts now used being generally 3 inches, laid on a foundation of Portland cement concrete.

367. Other materials used at the present time for paving carriageways are wood, asphalt, brick, tar-macadam, many kinds of artificial stone and blocks, and ordinary road metalling consolidated by steam-rolling.

Where the vehicular traffic is very heavy, and the annual cost of maintenance and scavenging is consequently high, it is desirable to adopt either of the paving materials already mentioned, so as to provide a harder and more durable surface, and construct a more permanent roadway than can be made by ordinary macadam.

368. In this country, authorities on the subject fix the limit for traffic at 40,000 tons per yard-width of road per annum, and for maintenance of macadamized roads, including cleansing and watering, at 2s. per square yard annually. When these figures are reached, that description of pavement should be adopted which is most suitable to the location of the thoroughfare and the class of traffic passing over it.

It should also be remembered that certain specific interests have to be considered in dealing with this somewhat complicated question. The principal points in connection with this are: first cost of construction and maintenance; description of material in relation to noise, dust, and mud; ease of traction, or the economical conveyance of merchandise, and wear and tear of horses and vehicles, as well as safety in travelling. The interests of owners of horses and vehicles, especially motor cars, who are the principal users of the streets, also merit important consideration. Ease of traction, or the economical conveyance of merchandise, has to be considered, as has also the immunity from accidents by falls—that is, the comparative safety in travelling. Neglect of these considerations, and the consequent damage to horses' legs and hoofs, will necessarily represent a considerable loss of money annually, and attention to them a proportionate diminution of loss.

Economy in the ultimate cost of construction and maintenance is of considerable importance, and affects the ratepayers directly, while noiselessness and absence of dust or mud affect pedestrians, business people, and shopkeepers. On the other hand, good foothold and smoothness affect all those who own horses and vehicles.

369. Some of the essential features which a good pavement for the carriageways of cities and towns should possess may be summarised as follows:—

(1) It should be impervious.

(2) It should be suitable for varying gradients and afford good foothold for horses.

(3) It should be durable, moderate in first cost and subsequent annual repairs, have sufficient curvature to throw off surface water rapidly, and be non-absorbent and easily cleansed.

(4) It should be as noiseless as possible.

(5) It should be constructed with a sufficient foundation for the class of traffic which it has to bear, so as not to subside under the influence of heavy loads.

(6) It should present a uniform and smooth surface, so as to allow of easy traction.

The conditions enumerated affect those interested in a varying degree; consequently the usual difficulty is to carry out one or two of the essential requirements without sacrificing the individual interests of the inhabitants.

The details referred to affect the several kinds of pavement differently, and will therefore be described under each separate class.

370. A pavement which is eminently suitable for the thoroughfare of a provincial or agricultural town will not, in the generality of cases, be appropriate for the carriageway of a city or manufacturing town, where the streets are subjected to a heavy and continuous traffic. Neither the physical features of a town, nor the climate, should be lost sight of in determining the pavement best adapted to a street or carriageway.

As illustrating the effect of traction on some of the different kinds of materials used, the following table, now universally adopted, may be given, previous to describing in detail the construction of the several pavements made use of at the present time for provincial and metropolitan street traffic.

TABLE XXXIX.

Traction on level roads formed of different materials, asphalt being taken as the standard of excellence.

Asphalted roadway, ...	1·0
Paved roadway, dry and in good order, ...	1·5 to 2·0
,, ,, in fair order, ...	2·0 ,, 2·5
,, ,, ,, but covered with mud, . .	2·0 ,, 2·7
Macadamized roadway, dry and in good order, . . .	2·5 ,, 3·0
,, ,, in a wet state, ...	3·3
,, ,, in fair order, ...	4·5
,, ,, ,, but covered with mud, .	5·5
,, ,, with the stones loose, . . .	5·0 to 8·2

Another useful table, prepared from experiments made by Mr Amos on different descriptions of pavement in the city of London, is also included:—

TABLE XL.

Road Material.	Speed in miles per hour.	Draught in lbs.	Fraction of load.	Tractive force in decimals of the load.
Gravelly macadam in a side street,	6·945	126·6	$\frac{1}{45\cdot3}$	·0219
	3·45	114·322	$\frac{1}{50\cdot3}$	·0197
Granite pitching by side of tramway,	5·15	70·963	$\frac{1}{81\cdot1}$	·0123
	3·196	41·932	$\frac{1}{137\cdot3}$	·0072
	2·557	45·572	$\frac{1}{121}$	·0082
Granite macadam 'freshly laid,'	4·239	262·886	$\frac{1}{21\cdot9}$	·0456
	2·775	242·726	$\frac{1}{23\cdot7}$	·0421
Asphalt pavement,	5·025	91·525	$\frac{1}{64\cdot9}$	·0158
	3·56	69·753	$\frac{1}{82\cdot5}$	·0121
	5·687	84·268	$\frac{1}{68\cdot3}$	·0111
Wood pavement,	3·932	118·163	$\frac{1}{48\cdot7}$	·0205
	3·278	102·412	$\frac{1}{56\cdot2}$	·0177
	3·827	100·066	$\frac{1}{57\cdot5}$	·0173
Macadam road (very good) on Victoria Embankment,	6·65	109·06	$\frac{1}{52\cdot7}$	·0181

371. **Boulder or Cobblestone pavements** at one time formed the principal paving, and still exist to a considerable extent in some of the cities and provincial towns in England. They afford a fairly good foothold for horses, but the roughness of the surface makes travelling over them very unpleasant, and causes excessive vibration.

This paving, which possesses the merit of cheapness, is easily displaced by the action of the traffic and frost, owing to the irregular shape of the stones, and the large joints necessary, while, at the same time, a considerable expenditure of tractive energy is required to move loads over them. For the same reasons, as already mentioned, it is almost impossible to keep the surface in a clean and sanitary condition.

372. It was also found that the increasing vehicular traffic in many of the larger towns entailed a greater cost for maintenance each year, while the discomfort and noise of the boulder pavements, the irregularities caused through wear on macadamized roads, and the production of mud and dust during certain seasons of the year, led to the substitution of a more suitable

class of material in the form of 'cubed granite' or 'setts' for making carriageways and streets.

This class of paving was first introduced into London in 1824 by Telford and laid in Hanover Square, although it is recorded that a pitched pavement was constructed in this city in 1762, replacing an old cobblestone pavement. The stones or setts then used were much larger, compared with the practice at the present time, being generally from 6 to 8 inches wide, 9 inches deep, and 12 inches long.

The earlier pavements laid in London and other towns were constructed in the following manner:—After the soil had been removed to a proper depth and the foundation properly prepared, a substratum of metalling or hard core was spread generally to a thickness of from 9 to 12 inches; in streets, however, which had to bear the heaviest traffic, the bottoming was increased in thickness to 15 inches. On this stratum was spread a coating of sand in which the setts were bedded. The principal thoroughfares in London at that period (1828 to 1838) were laid in this manner, the setts being of Aberdeen granite, 6 to 7½ inches wide and 9 inches deep.

This class of pavement had a life of from fourteen years in Fleet Street to twenty-four years in Cannon Street; the first cost averaged from 11s. to 17s. per square yard, while the amount expended annually for repairs up to the year 1840 was 1¾d. in the former street and 1d. per square yard in the latter thoroughfare. In the year 1854 the annual cost of maintenance had risen to 3d. per square yard in Fleet Street.

These paving setts when lifted were re-dressed and used again in some subsidiary street where the traffic was not heavy. There the paving had a further life, extending in some instances to about fourteen years, making a total duration of about thirty years.

In many cases the paving setts were laid directly on the subsoil, after this had been formed to a proper contour, and the joints were filled with sharp sand or fine gravel.

The dimensions of paving setts were reduced about the year 1850 to 5 inches in width, subsequently to 4 inches, and then to 3 inches, which, with a depth of 7½ inches and a length not exceeding 12 inches, are, with a few exceptions, the standard sizes of paving setts employed at the present time.

The system of laying the paving direct on the prepared ground or even on a loose stratum of hard core, although still followed in many instances, has been gradually superseded by forming the foundation with Portland cement concrete. The thickness and strength of this class of foundation is regulated according to the amount and class of the traffic which has to be accommodated.

373. The 'Euston Pavement.'—One of the first really good pitched pavements made in London was that known as the 'Euston Pavement,' which was constructed in the following manner:—The ground was prepared to the requisite depth and had the same curvature as the surface of the intended roadway when finished. Upon this prepared ground a coating of coarse gravel was spread 4 inches in thickness and well rammed. On this layer another coat of gravel, mixed with a small quantity of chalk for binding, was spread and rammed. On this stratum was placed another coat of fine gravel, upon which foundation the setts of Mount Sorrel granite were laid, bedded in 1 inch of fine sand. The size of the stones was 3 inches square and 4 inches deep, hammer-dressed and squared, set close together and laid at right angles to the kerb. The stones were thoroughly rammed by the pavior, the whole surface being finished by spreading over it screened gravel, which was allowed to find its way into the joints by the action of the wheel traffic, thereby steadying the whole pavement. The cost of this pavement, including foundations, is stated to have been 12s. per square yard.

374. Width of Carriageways.—The width of carriageways in cities and provincial towns varies according to the requirements and character of the traffic, and may be from 16 to 40 feet, a multiple of 8 feet generally being adopted, which is considered ample for fast travelling vehicles to pass each other safely.

Width in Relation to Traffic. Congestion of Street Traffic.—The congestion in many streets from the enormous expansion of the traffic in the leading thoroughfares of London and other cities is becoming more serious every year. This state of matters has called forth an expression of opinion that new main thoroughfares should be constructed having a width of from 80 feet to 125 feet, diverging in different directions, in order to adequately accommodate the increase of wheel traffic, which is becoming greater every year, and, in many instances, is becoming unmanageable. With this greater width the vexatious delays experienced at present would be greatly reduced, if not altogether removed.

At the present time the general practice in London and in many other large towns, where the wheel traffic is continuous, is to widen the carriageways at the intersections of the streets, which, in addition to providing space for refuges or resting places for the convenience of pedestrians crossing the thoroughfares, regulates and expedites the movements of vehicles at these points.

Wide streets add materially to the health of the inhabitants, and, in a measure, remove the crowded appearance so common in many old towns, while the greater space between the buildings gives dignity to the thoroughfares and an air of comfort to the surroundings.

375. Gradients and Contour.—For the purposes of wheel traffic the best form of longitudinal and cross-section would naturally be that of a level plane, as any inclination produces friction and consequently necessitates additional force for traction, and causes greater wear and tear of horses and vehicles. As, however, the surface water must be drained rapidly from the thoroughfare, especially after a heavy rainfall, a certain amount of inclination, both longitudinally and transversely, is necessary. The contour usually given to a street varies from $\frac{1}{40}$ to $\frac{1}{80}$ of its width, that is, between the kerb on each side, according to the longitudinal gradient, while in many cases a radius of 300 feet is adopted. This latter, on a carriageway 40 feet wide, gives a rise of 7½ inches at the crown, which, however, is excessive under normal conditions. On this width of thoroughfare a rise of 6 inches is considered sufficient, increasing at points to 7 or 8 inches, where gullies are placed to collect and dispose of the surface water.

The standard contour adopted in Liverpool, where pitched pavements are almost exclusively used, is shown in fig. 133, the rise or versine being fixed at 1 in 48 from the channel to the crown.

The longitudinal section of a street should, whenever practicable, have a gradient of not less than 1 in 120 to 1 in 150 in order to give effective and speedy drainage at the channels, but when the gradient is less a greater number of gullies will be necessary to properly discharge the surface water. On very hilly carriageways, owing to the great rush of surface water after a heavy rainfall, a larger number of gullies of greater capacity are likewise necessary to intercept the water and detritus, compared with streets having only a moderate gradient.

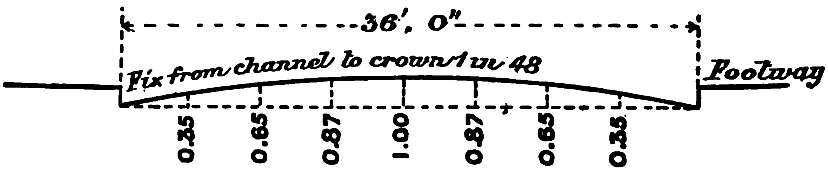

FIG. 133.—Contour adopted for streets in Liverpool.

The crown level longitudinally should be uniformly maintained, if at all practicable, from street to street in order to avoid undulations which greatly interfere with the free passage of vehicles.

376. The situation of an existing street, owing to the topographical features of the locality, does not always admit of a comprehensive system of gradients being established. In villages and suburban districts, which, in the course of time, may be merged within the boundaries of an adjoining town, the widths and gradients should be adjusted previous to the process of improvements and re-building operations being commenced, which sooner or later will in all probability take place.

The difficulty of obtaining suitable gradients in many cases is very great, especially where an existing building has been erected so as to avoid under-building, and the floor level of which may be either too high or too low for any prospective improvements in the gradient of the street. Excessively deep cuttings or high embankments which, if executed to give a uniform and easy gradient, might affect the value of adjoining property, may demand steeper gradients than would be permissible under ordinary circumstances.

It should be the aim of those in authority to endeavour to fix a system of gradients convenient for the traffic generally, rather than to consider the interests of particular individuals.

In most instances the work of construction in forming streets is undertaken and carried out by contractors by an offer at schedule prices, so that detailed information as to the different methods adopted by them in executing the work is not considered necessary. The more important operations and other relative matters will be dealt with when it is considered essential to further elucidate the general description of any particular class of work.

377. Formation of Carriageways.—The ground on which the street is to rest is prepared by excavating or making up, as may be found necessary, to the lines and levels shown upon the suggested plan and section. This applies both to new and the re-making of existing carriageways, except in the case where concrete has already been employed as a foundation, the ground being made thoroughly solid by steam-rolling. When a soft or unsuitable subsoil is met with in the bed of the roadway, it should be removed to such an extent and depth as may be found necessary, the voids being replaced with hard sound material. Where it is necessary to embank the roadway, the filling should be done in layers not exceeding 6 inches in thickness, well pounded or rolled, water being applied in some instances after each layer has been deposited to aid consolidation.

The depth of excavation or height of embankment, or the general levelling of the ground, is determined beforehand by fixing gradient or boning pegs at the formation level of the roadway. Previous to commencing the construction of the foundation, whether of concrete or any other material, gradient and contour pegs of wood or iron, generally the latter, are fixed at regular distances of from 5 to 8 feet apart between the kerbs or channels on either side of the roadway. These pegs are fixed so that the top of each represents the finished surface of the carriageway, while a distinctive mark or a second peg at the side of the others indicates the depth of the concrete or other material forming the foundation.

In ground of a retentive nature, or where there is any likelihood of water gaining access to the foundation, subsoil drains, properly trapped, should be formed and connected to the main drain. These subsoil drains are generally placed under the kerb or channels, the trench being filled up to formation level with small stones.

378. Foundations.—This is one of the most important items in connection with paved streets, no matter what the description of material may be which is to form the wearing surface. A good foundation, with a well-selected paving material, gives excellent results under traffic, while an inferior under-structure, even when the paving itself is of the best description, has the effect of producing a defective roadway. The paving material itself is generally made responsible for the bad results, however excellent the former may be, and many inferior descriptions of coverings have, in comparison, been lauded because they have been laid on a good foundation. No good results can be attained unless the under-structure is made of the best materials and forms a rigid base. The paving material forms the wearing part, or veneer, which may be renewed from time to time.

Experience has shown that the best foundation for any class of paved roadway is (1) Portland cement concrete, although many other kinds of material are employed, including (2) bêton, (3) bituminous concrete, (4) hand-set rubble bottoming, and (5) macadam or gravel and furnace cinders consolidated by steam-rolling.

Portland Cement Concrete Foundations.—For first-class work on thoroughfares bearing a heavy traffic, the best foundation is Portland cement concrete composed of from four to five parts by measure of gravel or stones, generally metalling, and one or more parts of clean sharp sand mixed with one part of cement. When this proportion is adopted, concrete, laid to a thickness of from 6 to 9 inches, is considered sufficient; but should a weaker composition be employed, consisting of six parts of stone, two parts of fine gravel or sand mixed with one part of cement, then the thickness must be increased. Where the carriageway is subjected to a less heavy traffic, 6 inches of concrete mixed in the latter proportions is generally regarded as sufficient for the purpose.

The foundation of a paved street takes the weight of the traffic and gives stability to the pavement. Portland cement concrete, if composed of good materials and carefully spread, will practically last for generations.

379. (1) **Preparing Portland Cement Concrete.**—The material, independent of the proportions adopted, is prepared by being mixed on bankers or boarded platforms of suitable size, sufficient to admit of the concrete being turned over the requisite number of times in one direction, and at the same time allowing three batches to be prepared at the same time.

The materials should be gauged in boxes of a size necessary to secure the proper proportion of the ingredients, which are then heaped up together and turned over twice in a dry state, once while being watered, and three times when wet before being loaded into barrows or cast upon the formation bed. When mixing the ingredients, the water should be added in a careful manner through a finely perforated rose nozzle, under very moderate pressure and in limited quantities, so as to obtain a thoroughly plastic and incorporated mass. The concrete should be thoroughly consolidated *in situ* with heavy beaters, formed to the proper contour of the street and smoothed over with a flat shovel, so as to present an even surface for the setts to be bedded on. Any irregularities which may appear on the surface after the concrete has been placed in position should be made good with fine material before the concrete proper has set or become hard.

Concrete should be deposited in position immediately after being mixed in a wet state, otherwise it may become partially set, and will therefore be of inferior strength.

The surface of a concrete foundation after completion is, according to the nature of the weather, sprinkled with water from time to time, to assist the ultimate hardening of the mass. In hot weather, or during the prevalence of frost, the surface of the concrete should be protected by being covered with old cement bags. When the former condition of weather prevails, it is usual to saturate the bags with water until the whole mass is thoroughly set.

Portland cement concrete foundations are generally allowed to remain from eight to ten days so as to properly set before the laying of the paving is commenced. The exigencies of the traffic, however, occasionally demand that the time occupied in executing the work should be shortened. This necessarily means that the proportion of cement to the other ingredients should be increased, and consequently adds to the cost of the work. The laying of the setts may be commenced the day following, but it is advisable, even when the stronger proportioned concrete is adopted, to allow it six clear days to harden before proceeding to lay the paving.

The Portland cement used for concrete foundations is generally specified to bear a tensile strain of not less than 350 lbs. to the square inch, after having been gauged neat with about 20 per cent. of its own weight of water and allowed to stand one day in air and seven days in water. It should be ground so finely that not more than 15 per cent. residue is left on a sieve of 5800 meshes per square inch. The storing of cement is of great importance, and it is usual for the engineer or surveyor to procure a sample of each consignment for the purpose of testing it before it is used.

380. (2) **Bêton.**—This description of foundation is also used for pitched pavements. It has been adopted in Liverpool, and is thus described by Mr. H. Percy Boulnois, formerly the City Engineer there*:—

"The ground having been prepared in the usual way, and the channel and kerb stones fixed in position, a stratum of stones (which should by preference be of a non-absorbent character), broken so as to pass all ways through a 3-inch ring, is spread evenly over the surface of the ground, and upon this is placed a layer of cement mortar mixed in the proportions of one of Portland cement to six of fine, sharp, clean gravel, in the method to be described hereafter. Upon this layer of mortar is placed another layer of broken stone—the whole of the stones in each layer to be thoroughly watered while the work is proceeding—and this stone is forced into the interstices of the first layer by the use of flat beaters of wrought iron weighing 16 lbs. each, shaped like square shovels with handles at an angle of 33°.

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* *Carriageways and Footways*, by H. Percy Boulnois, C.E.

"This process is repeated until the proper level and contour is reached, and the surface is finished off parallel to the exact curvature of the carriageway. The foundation thus prepared is left until the concrete is sufficiently set or hardened to receive the pavement, which, if possible, should not be less than ten days, although this period may be shortened, when the exigencies of the traffic render it imperative, by strengthening the proportion of cement to the gravel, care to be taken in all cases to periodically water the surface of the concrete to assist the ultimate hardening, and in very hot weather it is advisable to cover the surface of the concrete with old cement bags thoroughly saturated with water.

"The proportions of broken stone, gravel, and cement used in such a concrete are as follows:—

"Before mixing—Broken stone, eight parts; gravel, six parts; cement, one part.

"After mixing—Broken stones and gravel, mixed together, eleven parts; cement, one part; three parts of gravel having been expended in filling the interstices of the stones."

381. (3) **Bituminous Concrete.** — Another description of foundation extensively used as a substitute for cement concrete is that known as bituminous concrete. It is carried out, after the usual levelling of the ground has been completed and steam-rolled, by spreading a coat of metalling 6 to 9 inches thick, and consolidating it in a dry state by ramming or by rolling. The metalling should be composed of clean broken stone of a size to pass a 2½-inch or 3-inch gauge, and be in a thoroughly dry state. A boiling mixture of pitch, tar, and creosote oil is then poured or floated over the entire surface until all the interstices are filled, and over that a thin layer of small stones or chippings is spread and then thoroughly rolled when the mixture is in a semi-liquid state, so as to effectively incorporate and consolidate the whole mass and form a smooth, uniform surface. The bituminous mixture for this class of foundation is generally applied in the proportions of three of pitch to one of tar, or three and one-half of pitch to one-half of creosote oil. As, however, the composition of the ingredients varies to a considerable extent, the proportions must necessarily be modified accordingly. A cement concrete foundation is undoubtedly superior to that made with a bituminous mixture, but the latter, although more expensive, possesses the great advantage that it admits of the surface being used for laying the paving immediately after it is finished. This class of foundation is therefore adopted occasionally

in busy thoroughfares, where the stoppage of traffic for a considerable length of time would cause great annoyance and obstruction to business.

382. (4) **Hand-set Rubble Foundations.**—This method of forming a foundation for paved carriageways is similar to that employed in connection with macadamized roadways, and generally known as Telford's system. The hand-set foundation, or bottoming, consists of a layer of single rubble stones of a uniform depth, varying from 8 to 10 inches, set by hand to form a close, firm pavement. The stones should be laid with their broadest sides downwards in parallel lines across the street, breaking joint as much as practicable. The width of the upper part of the stones ought not to be more than 6 inches nor less than 4 inches, while they should not exceed 12 inches in length. After having been set closely together, the stones should be firmly wedged up by inserting an iron bar in all possible places, and fixing between the stones thus parted other pieces as nearly as possible of the same depth as the pavement or foundation, until the whole is firmly bound in position. Any projections formed by the pinning pieces above the regular pavement should be broken off, care being exercised, however, not to disturb or loosen the hand-set pitching. It is advisable not to carry on the wedging operations within a distance of 20 feet from the face of the work being laid. The small interstices should be filled with granite or whinstone chippings, or with pea gravel ½ inch to 1 inch gauge, watered and steam-rolled until a perfectly even contour and smooth surface is obtained. Any surplus binding material should be swept off, so as to leave a clean hard surface on which the paving is to be laid.

383. (5) **Macadam, Gravel, and Cinder Foundations.** — Many old macadamized roads which have a sufficient thickness of metalling are at times utilized, where the level of the surface permits, as a foundation for laying a pitched pavement upon. Traffic-consolidated roads are not to be depended on, and are invariably lifted and the material screened either to be made into concrete or to be re-applied and consolidated by rolling, the large percentage of small or useless material and detritus being thus got rid of.

The method generally adopted, however, is to spread a coat of 3-inch gauge metalling so as to give a thickness of 6 inches when consolidated, the manner of accomplishing which is fully described in Part I. of this treatise (Chapters VII. and VIII.). This makes a very efficient and cheap substitute for concrete, and as long as the subsoil is kept free from water and the surface drainage properly attended to, good results may be looked for in adopting this class of foundation. Coarse gravel of a sufficient thickness, to which is added, at times, a small quantity of chalk, makes a very good bottoming, and is principally used where such material can be obtained locally. It seldom occurs that a town is situated where the subsoil is composed of this material. Norwich, however, is an exception, the strata being made up of gravel and chalk, which forms a rough natural concrete on which, with the usual bed of sand, the paving is laid, dispensing with the foundation of artificial concrete. The natural surface or bed of many streets in some parts of Norwich is, to prevent local subsidence, treated by making or converting the foundation into concrete by flushing the gravel with Portland cement grout.

Furnace cinders, or clinkers, are extensively used in some of the manufacturing towns in England as a foundation for pitched pavements, and this class of material, which at one time was much used in Scotland, is now rarely employed as a foundation for street paving. The results obtained are said to be fairly good, and, of course, the first cost is reduced to a minimum.

384. Paving Setts and laying a Pitched Pavement.—Many considerations enter into the selection of rock for the purpose of making reliable paving setts. It should be durable under ordinary conditions of wear, possess hardness and cohesion as well as chemical stability in its constituent minerals. The balance between the resistant minerals, quartz and felspar, and soft minerals, hornblende, mica, chlorite, and other decomposition-products, may be stated as about 80 per cent. of the former and 20 per cent. of the latter. The cohesion involves the binding of the mineral grains or crystals, or, in other words, the structure of the rock; the toughness of the minerals also enters into the question. Setts should retain a rough surface in wet or dry weather. The surface roughness is generally obtained in rocks having a certain coarseness of grain. A too fine-grained sett invariably becomes polished under wear, while very coarse-grained stones may defeat the end in view owing to the generally prevailing yielding character of the minerals in such kinds of rock, especially when its proportion to hard minerals is excessive.

Uniformity of wear is also an essential property in paving setts. Should a rock contain a large amount of easily weathered or softened mineral, it will under traffic be subjected to the increased influence of denudation and concussions through heavy loads, which will cause unequal wear.

Previous to describing the method of laying and jointing a pitched pavement, it may be advisable to give the following particulars in regard to the different sizes of stone used in making this class of street covering, embracing setts, cubes, and blocks, and the area which one ton weight of each class will cover in square yards (see Table XLI., page 355). It must be remembered, however, that the specific gravity of the stone employed may vary considerably, consequently the area covered, as stated, is a broad average.

Cubes and blocks are extensively used for crossings, and on streets where there is a considerable gradient the greater number of joints, compared with ordinary paving, gives, under most circumstances, a better foothold for horses, the hoof having but a little way to slip before being arrested by a joint. On the prepared foundation a layer or cushion bed of fine gravel or clean sharp sand, one-half to one inch thick, is spread, and on this the paving-stones are laid. This provides, in a measure, an elastic bed, and distributes the pressure equally over the foundation supporting the pavement.

TABLE XLI.

*Showing size of different stones adopted for pitched pavements with the superficial area which one ton will cover.**

Stone.	Depth. Width. Length.	Area in square yards which one ton will pave.
Setts, . . .	5 in. × 3 in. × 5 in. to 7 in.	4·5
,, . . .	5¼ ,, × 3¼ ,, × ,,	4·3
,, . . .	6¼ ,, × 3¼ ,, × ,,	3·6
,, . . .	7¼ ,, × 3¼ ,, × ,,	3·1
Cubes, . . .	3¼ ,, × 3¼ ,, × 3¼ in.	6·7
,, . . .	3½ ,, × 3½ ,, × 3½ ,,	6·2
,, . . .	3¾ ,, × 3¾ ,, × 3¾ ,,	5·8
,, . . .	4 ,, × 4 ,, × 4 ,,	5·4
Blocks, . . .	4 ,, × 4 ,, × 6 ,,	3·6
,, . . .	4 ,, × 3 ,, × 3 ,,	5·4
,, . . .	5 ,, × 3 ,, × 3 ,,	4·4
,, . . .	6 ,, × 3 ,, × 3 ,,	3·7
,, . . .	6¼ ,, × 3¼ ,, × 3¼ ,,	3·25

The stones should be carefully gauged and coursed, laid in perfectly straight lines at right angles to the centre line of the roadway, and set hard with proper bond, every stone breaking joint with contiguous ones. The surface of the setts is generally laid ¼ inch to ½ inch above the finished level, and any four courses taken together should not measure more than 14 inches for 3-inch setts, and 16 inches for 3½-inch setts, from centre to centre of the joints. The stones to be used should be sound quarried granite, syenite, whinstone, or other approved material of uniform colour, and procured from quarries producing stone of equal quality and durability. When, as sometimes happens, stones from two or more quarries are introduced to expedite the execution of the work, they should be kept separate when laid. All stones should be brought to a regular rectangular shape with a reel head and dressed to the dimensions specified.

Paving setts are sometimes laid diagonally to the line of street, or, as it is termed, in 'herring-bone' fashion, which admits of the stones wearing in a more regular manner, though the foothold is not so good, and it is more expensive to lay.

385. The jointing of a pitched pavement demands special attention, as on its proper performance the stability and life of the paving will to a great extent depend. The most efficient method of laying setts on a concrete foundation is to bed the stones on a cushion of fine cement concrete when in a plastic condition, and fill the joints with Portland cement grout. This makes a very rigid structure, but is practically very noisy, and there being no elasticity, the vibration caused by heavy loads passing over the paving tends to crack and disintegrate the cement joints, with the result that the percolation of water takes place. It is now, however, generally admitted that filling the joints with an asphaltic composition is superior to any other method in effecting this. The grouting of the joints with such a mixture not only makes them impervious, but greatly diminishes the noise inseparable from this class of pavement. To ensure good results bituminous grout must be applied under suitable conditions, cold and wet weather being detrimental to its proper execution. The success of pitch grouting depends to a great extent on the experience of the person in charge of the apparatus employed for mixing and boiling the composition. If the composition is too hard, it will pulverize in cold weather, while if too soft it will run and become sticky in hot weather. The object to be attained in asphaltic grouting is to make the paving impervious to moisture and to induce a bond between the setts with a degree of elasticity sufficient to prevent it from cracking. Pitch grout, when properly manipulated and applied, possesses the quality of becoming sufficiently hard in a few hours after making the joints, so that traffic may be permitted over the pavement shortly after completion.

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* *The Municipal and Sanitary Engineer's Handbook*, by H. Percy Boulnois, C.E.

The method of effecting this kind of joint is by filling the space between the setts with clean dry shingle or chippings, small enough to pass through a ⅝-inch riddle, but not so small as to pass through ¼-inch mesh, and entirely free from dust or foreign matter. When the joints are filled, either by the material being brushed or scraped into them, the setts should be carefully beaten down to a solid bearing having a uniform surface, and the joints again filled, the shingle or chippings being so regulated as not to reach a greater height than one inch from the surface. The last application of shingle or chippings must be perfectly clean, for which purpose the screening should be performed in water, and the material then dried in a kiln or by some other suitable means until thoroughly free from moisture. After being worked into the joints, and previous to applying the bituminous grout, care should be taken to keep the chippings or shingle perfectly dry, for which purpose the paving should be covered with tarpaulins when necessary. The pavement being now ready for grouting, the joints are filled flush up to the surface with the asphaltic mixture applied in a boiling state. This is done with a lipped can, care being taken to avoid leaving any of the composition on the surface of the setts. Grouting the joints should be carried out at least six feet away from the paviors at work. The whole surface of the pavement is subsequently covered with a thin coating of sharp sand, which completes the operation.

The composition of bituminous grout for paving purposes varies in different parts of the country according to the composition of the ingredients and the climatic conditions. In ordinary circumstances the preparation may be made in the following proportions, namely, one part of pitch to one part of tar, or three of pitch to one of creosote oil. Care and judgment must be exercised, however, so that the mixture will be of such a consistency as to set hard in a few hours after being used, and yet not be brittle. Should any delay occur in the application of the mixture when sufficiently boiled, the proper proportions and consistency must be maintained by adding extra tar from time to time.

386. Cement Grout.—The operations in applying cement grout are similar to those described in the preceding paragraphs. The joints are first filled with chippings or shingle worked in by means of a cramming-iron; the whole surface of the paving is then covered with grout, consisting of Portland cement, or lime and sand in the proportion of one part of cement or lime to one or one and a half parts of sand, and brushed into the joints with a stumpy broom.

The joints of a pitched pavement grouted with cement or lime mortar require a considerable time to set and adhere properly to the setts, generally from five to six days. The slightest disturbance caused by vibration or the passage of vehicles over them when the grout is in a green state will seriously affect its efficiency as an impervious pavement. Any yielding of the foundation or subsoil, or the effect produced by heavy individual loads passing over the pavement, will tend to disintegrate the material forming the joint and allow surface water to find its way to the under bed of the pitching, which will adversely affect the durability of the pavement. Filling the joints with cement or lime-grout can be carried out at any time except during the prevalence of frost.

387. Forming the Joints with Sand.—When the foundation is composed of metalling, gravel or furnace cinders, consolidated by steam-rolling, the joint-filling generally consists of rough sand or very fine gravel. The sand is usually washed and scraped into the joints, the paving being carefully beaten down to a firm unyielding bed and uniform surface, and the joints again filled flush. The sand should be washed into the joints by means of a small rose nozzle, and scraped or crammed in with a thin iron tool. As this kind of joint-filling material is pervious, it should only be adopted in streets where the traffic is light, as water percolating to the under-bed will, sooner or later, injuriously affect the foundation.

388. Advantages of Granite Setts.—Unquestionably a roadway paved with granite of good quality, properly laid upon a hard concrete foundation, forms the cheapest pavement of any in ultimate cost, and in a less degree with setts produced from basalt or whinstone, especially where the traffic is heavy. In many respects this form of street covering answers nearly all the requirements of traffic, and its great advantage, in addition to durability as a paving material, is that of affording good foothold for horses on steep gradients. It is also comparatively hygienic, yields but little dust or mud, and is fairly easily cleansed.

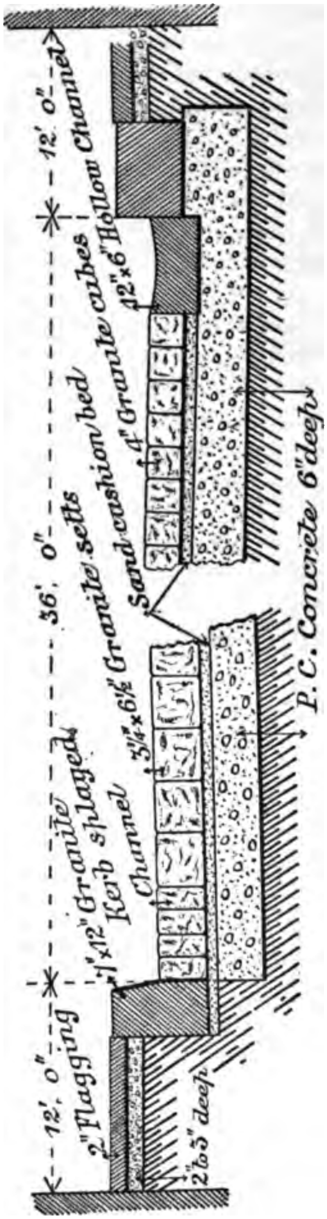

FIG. 134.—Cross-section of pitched pavement.

The life of a granite sett pavement varies with the amount and character of the traffic, but from fifteen to twenty-five years may be taken as the time that will elapse before it is necessary to renew the pavement. During this period, however, the setts will require to be lifted and the wearing surface re-dressed, and again laid.

389. Objections.—The objections to this pavement are not numerous, but they are far-reaching and important. The surface of a pitched pavement after being in use for some time becomes, under certain atmospheric conditions, very greasy and slippery. It is a paving which is detrimental to horses, and at the same time one which deteriorates and reduces the life of all rolling stock that passes over it. The incessant noise from the wheel traffic and the iron shoes of horses striking upon it is such that thoroughfares so paved cause great annoyance, amounting in many instances to an intolerable nuisance to business people or tradesmen whose premises adjoin or abut on streets so paved. This clearly points to the necessity, so far as noise is concerned, of employing some other kind of paving for carriageways in residential parts of towns, or where business premises and shops exist. For streets passing through manufacturing districts, the undoubted advantages of a pitched pavement greatly outweigh the defects mentioned. Fig. 134 shows a cross-section of a first-class pitched pavement.

390. Quality of Setts and Source of Supply.—Local circumstances often determine the kind of stone to be made use of as a paving material; consequently the cost of forming a pitched pavement will vary according to these circumstances and the distance from the source of supply. Great care and judgment are necessary in selecting stones as paving setts for any particular locality, and regard must be had to the class of traffic to be accommodated and the climatic conditions prevailing, especially when the material is obtained from any new source of supply. The igneous and metamorphic rocks of a hard description, and containing a certain percentage of augite or hornblende and orthoclase felspar, are those principally employed, although many other kinds of stone are used.

These generally comprise granite, syenite, basalt, whinstone, though paving setts are sometimes made from millstone grit and other sedimentary rocks which are used in districts where the traffic is light. Many of the hardest and most durable stones have been discontinued in London and Liverpool owing to the surface of these wearing smooth and becoming slippery, even under normal conditions of traffic and weather. This is notably the case with the old blue Penmaenmawr stone, which, however, is not now much used for setts, but is principally manufactured into kerbs and channels. On the other hand, Aberdeen granite setts are preferred in London to Mount Sorrel and Guernsey granite, although the latter is better in some respects, because the surface remains rough even after considerable wear. It is also much less expensive to cleanse than these and most other kinds of granite used for paving. Whinstone setts are greatly used in provincial towns where the traffic is not excessive, and a pavement made with this material, although it wears much faster than granite, invariably maintains a rough surface, and, consequently, does not become slippery like the granite already mentioned. These pavements are being gradually superseded in London by wood paving.

The principal sources of supply for granite and whinstone paving setts are described in Table XLII., page 360.

391. Besides these sources, capable as they are of furnishing all the material required in this country for the making and repairing of carriageways, a great quantity of setts, kerbs, and channels is annually imported from Belgium, Norway, France, Rotterdam, and the quarries on the Rhine worked by the London Basalt Stone Company.

392. Cost of Pitched Pavements — Earthworks. — The excavation, filling, and levelling depend entirely on circumstances, and no definite price per cubic yard can be stated for this class of work.

Foundations.—As already mentioned, the cost of providing a pitched pavement on a concrete foundation varies according to the locality where the work is carried out and the source from which the materials are obtained. The cost of Portland cement concrete does not differ much when suitable material can be obtained within a reasonable distance; 1s. 6d. to 2s. per square yard, 6 inches in depth, being the usual figures when the metalling or gravel can be procured for 4s. per ton. When this material has to be brought a considerable distance the price may rise as high as 9s. to 10s. per ton, in which case the cost for a similar thickness of concrete will amount to about 2s. 6d. or 3s. per square yard.

Table XLII.

Name of Quarry and Petrological Name of Stone.	Locality.
England and Wales—	
Mount Sorrel (Hornblendic Granite),	Leicestershire
Stoney Stanton (Syenite),	,,
Enderby (Syenite Porphyry),	,,
Bardon Hill (Felstone),	,,
Charnwood (Hornblendic Granite),	,,
Penmaenmawr (Quartz Diabase),	Carnarvonshire
Pwllheli (Diabase),	,,
Clee Hill (Olivine Diabase),	Shropshire
Shap (Hornblendic Granite),	Westmorland
Whinsill Dyke (Quartz Diabase),	Durham
Cleveland Dyke (Augite Andesite),	Yorkshire
Scotland—	
Aberdeen and District (Granite),	Aberdeenshire
Bonawe, Loch Etive ,,	Argyllshire
Crarae and Furness, Loch Fyne ,,	,,
Dalbeattie ,,	Kirkcudbrightshire
Creetown ,,	,,
Kilsyth (Dolerite),	Stirlingshire
Most of the counties in Scotland produce whinstone setts (Dolerite), those from which the greater quantity is supplied being Lanark, Fife, Midlothian, Ayr, and Dumbarton.	
Ireland—	
Newry (Granite),	Co. Down
Castlewellan ,,	,,
Arklow ,,	Co. Wicklow
Channel Islands—	
St Samson, Vale Castle (Varying from Hornblendic Gabbro-Gneiss to Enstatite-augite Diorite.)	Guernsey
Herm	,,
Ronez	Jersey
La Moye	Alderney

393. Bituminous concrete, for similar reasons, varies in price from 2s. 4d. to 3s. 3d. per square yard laid to a depth of six inches. The cost

of forming a foundation of pitched rubble or of metalling will be found in Chapter VIII., Part I.

394. Paving Setts.—The price per ton of paving setts delivered in any particular town depends on the dimensions to which they are dressed and the distance from the source of supply. The price per ton for the different sizes used in the construction of carriageways in London and four large Scottish cities is given in Table below:—

TABLE XLIII.

Source of Supply.	Setts 6 in. × 3 in. to 3½ in.	Blocks 5 in. × 6 in.	Cubes 4 in. × 4 in. × 4 in.
City of London—	*s.* *d.*	*s.* *d.*	*s.* *d.*
Aberdeen granite, . . .	36 0	30 0	36 0
Guernsey granite, . . .	30 0	26 0	30 0
Mount Sorrel granite, . . .	31 0	29 0	30 0
Enderby, ...	31 0	27 0	27 0
Glasgow—			
Crarae, Furness, or Bonawe (granite),	22s. to 28s.	26 0	25 0
Edinburgh—			
Kemnay, Aberdeen (granite), .	28 0	...	...
Ratho and Ravelrig Midlothian } (whinstone),	14 0	...	...
Dundee—			
Aberdeen granite, . . .	16 0	...	...
Pitroddie, Devonshaw, and St Margaret's (Inverkeithing) (whinstone), ...	12 0	8 0	16 6
Aberdeen—			
Rubislaw, Cairney, Cove, Kemnay, Dancing Cairns, Dyce, Corrennie, and Hill of Fare (granite), .	8 6	6 2	7 6

The price per square yard for the paving material will, therefore, be, at present prices, for setts in London 10s., and in Aberdeen 2s. 5d. per square yard, and for cubes, 6s. 8d. and 1s. 5d. per square yard respectively.

The cost per square yard of a sett pavement, including a concrete foundation, laying and jointing, will of course vary according to the price of the stones per ton and the wages paid in different cities and towns. The joint-filling averages about 1s. 2d. to 1s. 4d. for grouting with Portland cement mortar, and 1s. 6d. to 1s. 8d. for bituminous grout.

395. The amount expended in the annual maintenance of paved streets depends on the volume of traffic which the pavement has to sustain, and on other circumstances. It is necessary, for arriving at the ultimate or even the comparative cost, to give statistics of first cost and outlays for actual repairs executed from time to time, together with the cost of lifting and relaying the pavement once or twice during its actual or calculated lifetime, owing to the surface becoming irregular or depressions being formed.

The amount expended annually per square yard in cleansing the surface, a very variable item with the different kinds of granite employed, should also be included, while the sanding of the surface, especially on gradients, to afford better foothold under unfavourable conditions of weather, should, in addition, be embraced under this item.

The cost of cleansing the surface of a street paved with Guernsey granite amounts to 2½d. per square yard annually more than that in the case of a thoroughfare paved with Aberdeen granite setts. On some of the streets situated on a gradient in the City of London, the cost of sanding is stated to amount to about £6 per mile annually.

Aberdeen granite paving, although it wears under heavy traffic to a greater extent than Guernsey, is, nevertheless, eminently suitable for carriageways where a good and safe foothold is of primary importance, and particularly on steep gradients.

Paving setts which have been exposed to heavy and continuous wheel traffic for a number of years, when taken up for relaying are found in most instances to require a certain amount of re-dressing. This is caused by the wear on the top of the setts, the amount of which varies according to the nature of the stone, the manner in which the pavement was laid, their position in any particular thoroughfare, and the character of the traffic. Setts which have been laid with wide joints are found to be considerably worn or rounded on the arrises, to the extent of 1½ inches in some cases, which entails a large waste of material in re-dressing to a rectangular form.

This rounding of the arrises of sett-paved streets, especially on gradients, reduces the life of these pavements materially, and present, when worn, a very irregular corrugated surface, in addition to inducing insanitary conditions and adding to the cost of cleansing. In a measure this defect is due to the comparatively wide joints necessary in such paving, owing to the difficulty of procuring regular dressed setts free from projections. A method by which this defect can be eliminated has recently been introduced under the name of the "Standard" system;* it consists of thin metal strips about 3 feet long, placed between the longitudinal joints of the paving. These metal strips are placed in position previous to the bitumen or other jointing material being used.

Streets paved with the addition of this arris-preserving arrangement have, it is said, given satisfactory results. The abrasion of the edges, formerly inseparable from this kind of paving material, owing to irregularities and projections in the jointing surfaces, appears to be eliminated, or, at any rate, greatly reduced, and the surface, as a whole, wears more uniformly. Consequently, the life of the paving is considerably increased, cleansing is greatly facilitated, and the hygienic conditions improved. Fig. 135 shows the appearance of a street paved with setts, the arrises being considerably worn, and fig. 136 is a sketch of the "Standard" system with the arrises effectually protected.

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* Messrs. J. Hirst & Son, Cleckheaton, Yorks.

The cost of inserting these metal strips is, on an average, about 1s. 3d. per square yard above that of the ordinary method of laying a sett pavement.

The system may be adapted to any other kind of paving material where these metal strips would not create too wide a joint. The laying of any description of paving material relies on close jointing to give the best wearing results; anything exceeding ¼ of an inch produces a corduroy-like surface.

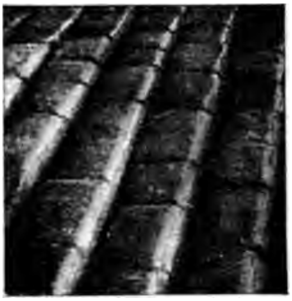

FIG. 135.

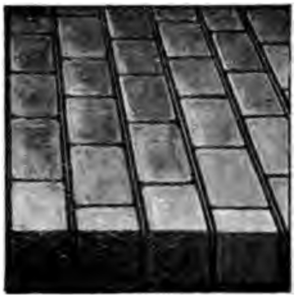

FIG. 136.

397. The following Table (XLIV.) gives the first cost, description of foundation and class of setts used, annual repairs, cleansing, and the lifetime of carriageways paved with setts, so far as can be obtained, in the chief cities and towns of the kingdom. The order is that of the population of the towns mentioned.

398. From this table it would appear that the average lifetime of a granite sett pavement in the City of London is eighteen and a half years, the longest being twenty-five years, while the shortest is in the Whitechapel district, where the life of this description of paving is stated to be only nine years. In the former two cases the pavement is taken up and relaid once during the period mentioned.

The cost of laying a sett pavement, including foundations, repayment of principal and interest, for 1 mile of carriageway 30 feet wide, taking the life of the paving at twenty-four years, and lifting and re-dressing the

TABLE

NAME OF TOWN.	First cost of sett paving per square yard.	Description of foundation and size of setts in inches.
1. London—Hammersmith, .	16s. including foundation.	P. c. concrete 6 in. deep, 5×7.
,, Holborn, . .	14s. 6d.	,, 6 ,, 3×7, A.
,, Lambeth, . .	13s. 7½d. on existing foundations.	,, 12 ,, 4×7, A.
,, Mile End (Old Town), . .	13s. 6d. ,, ,,	,, 6 ,, 3½×7.
,, Shoreditch, . .	16s. 6d. including foundation.	,, 6 ,, 3×7, A., G.
,, Stoke Newington,	,, ,,	,, 6 ,, 4×7.
,, Strand, . . .	14s. 9d. on existing foundation.	,, 6 ,, 3×9, A.
,, St Martin's-in-the-Field, Charing Cross, . . .	15s. ,,	,, 6 ,, 3×7, A., E., G.
,, St Mary, Islington, . . .	12s. 6d. to 13s. 6d. on existing foundation.	,, and blue lias lime 6 to 9 in., 3×6, A.
,, St Pancras, . .	14s. 6d.	P. c. concrete 6 to 9 in., 3×6, G.
,, Whitechapel,* .	14s. 7d.	P. c. concrete 6 in., 3×7, 3×9, A., G.
2. Glasgow, ...	Granite—13s. 6d. to 14s. 9d. including foundation. Whinstone—10s. 8d. to 11s. 4d. including foundation.	P. c. concrete 4 to 6 in. deep 3½×6 to 7, B., F. .. .. ..
3. Liverpool, ...	11s. to 13s.	P. c. concrete 6 in. deep, 4 in. cubes, and 3½×6½×5×7.
4. Manchester, ...	10s. 6d. including foundation.	Furnace cinders and pinned foundation, 3 to 3½×6.
5. Birmingham, ...	12s. ,, ,,	P. c. concrete 6 in. deep, 3×6.
6. Sheffield, ...	13s. 6d. ,, ,,	P. c. concrete 6 to 9 in., 3×5×6, and 4 in. cubes, A., D., M., P., L, W.
7. Belfast, ...	15s. to 20s. including foundation and re-setting kerbs, etc.	P. c. concrete 9 in. deep, 4×6.
8. Bristol, ...	14s. including foundation.	P. c. concrete 6 in. deep, 3×5, N., W.
9. Edinburgh, ...	10s. 6d. on existing foundations.	,, 6 ,, 3×4×7, A.
10. West Ham, ...	15s. 6d. including foundation.	,, 6 ,, 3×6 and 4×7, A., G.
11. Dublin, ...	14s.	P. c. concrete 6 in. deep, 3½×6, W.
12. Bradford, ...	12s. 6d. ,, ,,	,, 6 ,, 3×6, M., D., T., W.
13. Newcastle-on-Tyne, . .	11s.	P. c. concrete 6 in. deep, 3×6.
14. Leicester, ...	8s. 6d.	,, 6 ,, 3×5.
15. Bolton, ...	10s. 6d.	,, 6 ,, 3×6.
16. Dundee, ...	10s. 6d. to 13s. 6d. including foundation.	,, 6 ,, 4×3½×6, A., ,, Pitroddie, I.
17. Aberdeen, ...	11s. 9d. to 12s. 6d. ,, ,,	P. c. concrete 6 in. deep, 4 in. cubes and 3½×6, A.
18. Birkenhead, ...	.. .. ..	,, 6 ,, various, P.
19. Wolverhampton, . . .	11s. 3d. including foundation and excavation.	,, 6 ,, 4 in. cubes, and 3×7 on gradients exceeding 1 in 30.
20. Coventry, ...	12s. 6d. including foundation.	P. c. concrete 6 in. deep.
21. Bury, ...	12s. ,, ,,	,, 6 ,, 3×5, P.
22. Hanley, ...	10s.	,, 6 ,, 3×5×6, all sorts.

REFERENCE

A. Aberdeen. B. Bonawe. D. Dalbeattie. Ds. Devonshaw. E. Enderby. F. Furness. G. Guernsey.

* This table has been compiled from various sources. The prices in London and some other cities and towns

XLIV.*

Description of grouting.	Annual cost of maintenance per square yard : (a), repairs ; (b), cleansing and watering.		Estimated life of sett paving under heavy traffic.	REMARKS.
	a.	b.		
ime.	.. ..	.. ..	25 years.	.. .. ..
. cement.	.. ..	.. ..	.. ..	.. .. ..
,,	.. ..	.. ..	19 years.	Very heavy traffic.
ias lime.	Practically nothing for first 20 years.	.. ..	25 ,,	.. .. ..
. cement.	.. ..		20 ,,	.. .. ..
,,	1d. average for 3 years.	2½d.	15 to 20 years.	.. .. ..
,,	.. ..	.. ..	.. ..	Setts were worn 5 to 6 inches when lifted after 10 years' service.
,,	.. ..	.. ..	15 to 20 years.	Being replaced by wood.
. cement and blue lias, bituminous.	.. ..	.. ..	.. ..	.. .. ..
. cement and pitch.	.. ..	.. ..	20 to 30 years.	Renewal or re-dressing necessary to remove slipperiness.
,, (1 to 3).	.. ..	4½d.	9 years.	.. .. ..
,, and bituminous.	.. ..	.. ..	25 ,,	Other 25 years after re-dressing and relaying.
ituminous.	.. ..	.. ..	30 ,,	.. .. ..
,, stone and chippings.	½d.	.. ..	15 to 30 years.	.. .. ..
. cement.	1d.	4d.	25 ,,	.. .. ..
itch and tar.	.. ..	.. ..	20 to 25 ,,	.. .. ..
. cement and gravel.	*Nil* for first 10 years; 1d. afterwards.	.. ..	20 ,,	Other 20 years after re-dressing and relaying.
,, and bitumen combined.	About 5d. combined.	.. ..	18 ,,	Stones require to be re-dressed after this period of service.
,, and asphalt.	3d.	.. ..	30 ,,	.. .. ..
. cement.	.. ..	.. ..	.. ..	.. .. ..
ituminous.	1d.	10d. to 1s.	30 years.	Paved with good granite.
,,	.. ..	.. ..	20 ,,	.. .. ..
,,	.. ..	.. ..	24 ,,	Granite and whinstone.
,,	5½d. during life, including first cost.	1½d.	25 ,,	.. .. ..
roken stone with ballast or gravel.	2d.	.. ..	30 ,,	.. .. ..
. cement and bitumen.	3d.	.. ..	18 to 30 years.	Whinstone and granite.
,, ,, and chips.	.. ..	.. ..	Depends on nature of traffic.	Streets have lasted over 40 years where undisturbed.
ituminous.	.. ..	.. ..	.. ..	.. .. ..
itch and broken stone.	.. ..	.. ..	.. ..	Only been recently laid.
itch.	.. ..	3½d.	.. ..	Ditto.
. cement and pitch.	.. ..	.. ..	40 to 50 years.	.. .. ..
itumen finished with cement.	.. ..	.. ..	30 years.	.. .. ..

TABLE.

I. Inverkeithing. M. Mount Sorrel. N. Newry. P. Penmaenmawr. T. Threlkeld. W. Welsh.

refer principally to figures for work done some years ago, this class of paving being only now laid to a limited extent.

blocks and relaying after eighteen years' wear, may be stated as follows:—

TABLE XLV.

1 mile of carriageway 30 feet wide, 17,600 square yards, including foundations, jointing, etc., 15s. 6d.,		£13,640
Contingencies,		680
		£14,320
Lifting, re-dressing blocks, and relaying 17,600 square yards, 1s. 2d.,	£1,027	
Contingencies,	130	
		1,157
		£15,477
Repayment and interest on above sum for twenty-four years, including relaying at 3¾ per cent.,		6,861
Total sum,		£22,338

This represents an average annual cost during twenty-four years, including lifting, re-dressing blocks, and relaying, of 1s. 0·69d. per square yard, and adding 1½d. per square yard for repairs, but exclusive of cleansing and sanding, amounts to 1s. 2·19d. per square yard.

In large cities and provincial towns where the traffic varies from heavy to medium and light vehicular conveyances, the lifetime of a granite sett roadway is stated at from eighteen to forty years, while the annual cost, as detailed above, will average about 1s., 6d., and 6d. respectively, the first cost of the paving, exclusive of foundations, averaging from 12s. 6d. to 7s. 6d. per square yard.

These figures clearly show that the life of pitched pavements constructed alike in regard to foundation and description of materials used for making the setts is simply a question of traffic, and although statistics on this point are not available for all the towns referred to, still the inference points to that conclusion.

399. Small Sett Paving.—This form of paving, introduced into England from Germany, and known there as Kleinpflaster, has been experimented with in Lancashire in order to test its adaptability under the traffic conditions of this country. The stones, composed of basalt, are approximately of equal size, varying from 3½ to 4 inches, and from 4 to 4½ inches in depth, the regularity of which is important, and which is secured by means of a special machine, designed for cutting these stones, otherwise they may vary from square to triangular shaped heads, or practically random setts, and makes the surface a close-fitting mosaic. The best class of work in this description of paving is laid on a Portland cement concrete foundation; the small setts are then laid and the jointing filled with cement mortar, composed of 1 of cement to 3 of sand, or with a bituminous mixture. It is stated, however, that such a foundation is by no means necessary—in fact, it was with the idea of improving or armouring existing macadamized roadways that it was introduced into this country. For this purpose the surface of the road is first scarified and the loosened macadam carted off. The level of the surface is thus lowered about 6 inches from its previous height, and, when a certain area has been excavated, a gang of men go very carefully over the road-bed to make the contour as perfect as possible. The road-bed must be consolidated thoroughly, and is then spread over with small granite chippings, well watered, and finally compressed by a steam roller. Sand is next spread evenly over the road-bed, to a depth of about half an inch, which forms a foundation for the small basaltic blocks to be laid upon. The roadway is then ready for the paving setts. Before laying, each stone is measured by a pavior, and those measuring 3½ to 4 inches in depth are placed into a heap, whilst those slightly less are piled into another. The larger blocks are laid near the crown of the road, and the smaller ones are used at the sides.

In Germany, this description of pavement is mostly used for obtaining a better road during the winter months than that provided by ordinary macadam, which was not satisfactory.

400. The small setts are laid on the existing macadam surface after irregularities have been levelled and rolled. Sand is used sparingly for the purpose of maintaining a regular surface with stones of irregular depths. The arrangement of laying the irregular setts is in the form of a series of small arches springing from a longitudinal herring-bone bond. This form of arch construction is supposed to give greater strength to the paving, while it is also claimed that the loads are distributed more regularly over the surface of the roadway. The joints are filled with sand, which is spread over the surface and allowed to remain for a few days, so as to work into the joints.

The great novelty of this form of construction appears to be the low cost of production of the small setts made from basalt, a local stone. It is extensively used in several German provinces, chiefly in Hanover, Rheinland, Westphalia, and in many towns, notably Bonn, Cologne, Oberhausen, and Wiesbaden, where, probably, the best examples of this paving have been carried out.

The entire cost of this system is given as about 7s. per square yard, including an ordinary foundation, and as about 4s. 10d. per square yard laid on existing roads. These pavements have been down for varying periods, and appear to give entire satisfaction.

401. The advantages claimed for this method of paving, which practically forms an armoured roadway, are durability, absence of dust and ease of cleansing, excellent foothold, reduced resistance to traction compared with large granite setts, noiselessness, approximating to that of traffic on asphalt, and low first cost, varying according to the locality.

A small sett pavement of this description laid on a concrete foundation will undoubtedly make a good roadway, and the foothold, considering the number of irregular joints, will be better than an ordinary sett-paved street. The cost would be practically the same as that of ordinary sett pavements, as any saving in the price per ton of the paving stones would be counterbalanced by the necessarily increased quantity of jointing material, cement, grout or pitch required for the small sett paving.

The reduced resistance to traction, due to the stones wearing in a regular manner owing to the irregular joints, is a feature characteristic of sett-paved streets in this country laid in herring-bone fashion. This description of jointing is, however, very slippery during frosty weather. The cleansing is easier and more effective than on a macadam road, but there can be little difference in the cost of doing this on other pavements which are laid close-jointed and are in good repair. The noise, compared with large-sized sett paving, will necessarily be less, and the vibration will also be reduced.

402. This system of paving for armouring existing macadam roads suggests many considerations as to its suitability for this country. A paving of any description laid on an existing macadam road as a foundation with sand only as a jointing material to withstand heavy wheel traffic under all climatic conditions prevailing in this country requires close scrutiny. Such a paving must be totally devoid of surface drainage and the sand joints adversely affected during high winds. The rain falling on an ordinary macadam road is, of course, drained to the sides owing to its nominally waterproof surface and convexity, and providing the surface is in fair order, otherwise considerable damage is done to the crust of the road. On a small sett-paved roadway without the provision for surface drainage all the rain will be absorbed, and will drain through the practically open joints composed of ordinary sand to the surface of the old road, where it will either remain or soak into the macadam foundation. Moreover, from a hygienic point of view this system appears to be one which cannot be recommended under the method of construction described in the preceding paragraphs.

403. From this aspect of the subject, the method under notice would, contrary to all recognised procedure in road work in the past, nullify the attempts hitherto made and the endeavours of most road engineers at the present time to form a thoroughly waterproof surface as a solution of the question of preventing mud and dust, and at the same time of prolonging the life of macadamized roads.

This system has been introduced into England and carried out by Mr. Wheeler of the Welsh Granite Co., chiefly near Stockport, Lancashire.

It is, however, too early to pronounce any definite opinion in regard to its suitability to the requirements of this country, or as to the advantages claimed for it.

This form of pavement is somewhat similar to the random pitching and hornizing practised in many parts of this country years ago. These were not, however, very successful, owing probably to the absence of some virtue apparently possessed by the German stones, and especially by the sand as a jointing material.

CHAPTER XI.

WOOD PAVEMENTS.

404. The idea of constructing the carriageway pavements in towns with wood dates back about a century, though the first appearance of this description of paving in London occurred in the year 1839. Since this year a large variety of methods of laying the wood blocks have been introduced, and particulars of the earlier systems were given in the first edition of this work. The chief developments which have taken place in wood-paving have been in the direction of the size and shape of the blocks themselves, and in the kinds of wood employed. In the earliest contracts carried out the blocks measured 6 to 8 inches across, and from 3½ to 6 inches deep; in another instance the size of the blocks was 6½ to 7½ inches wide, 13 to 15 inches long, and from 8 to 9 inches deep. Some years later these measurements were considerably reduced, and approached very closely to the present size of the wood block. The different descriptions of wood employed included Baltic fir, pine, oak, elm, beech and ash, most of which find no place in modern wood-paving. In one or two instances, such as that known as the improved wood system introduced from America into London in 1871, the blocks were dipped in tar previous to being laid, while in what was known as the Ligno Universal pavement the wood underwent a process of "mineralization." From these earlier methods, therefore, the present principles characterising the systems of paving now in general use have been developed.

405. The chief descriptions of wood in use for paving carriageways at the present time are those which have come to be classified as softwoods and hardwoods. The softwood most largely employed is that of yellow deal. The nature of this wood being very absorbent, the method of creosoting was introduced in order to fill up the interstices, which has the effect of preserving the wood and making it more sanitary. In spite of this, however, it will be observed from the following Table (XLVI.), compiled from results obtained by Drs Gordon and Hake for the Agent-General for Western Australia, that it does not compare favourably with the hardwoods.

TABLE XLVI.

Analysis of aqueous extract of various paving blocks after use in traffic.

Description of Block.	Karri, 1893.	Jarrah, 1894.	Red Gum, 1889.	Deal, 1890.	Deal, Creosoted, 1899.
Ammonia, ...	·0008	·0016	·00016	·00016	·00112
Albuminoid ammonia, . .	·00113	·00145	·00140	·00103	·00314
Chlorides, ...	·020	·048	·072	·1	·028
Nitrates, ...	·0029	·0037	·0030	·0116	·0038
Oxygen absorbed from permanganate,	·158	·303	·232	·048	·588
Sulphates, ...	slight traces	strong traces	strong traces	strong traces	minute traces
Phosphates, ...	slight	minute traces	nil.	nil.	slight traces
Total solids in solution, . .	·32	·58	·68	·70	·74
(*a*) Organic, ...	·24	·41	·51	·40	·63
(*b*) Inorganic, ...	·08	·17	·17	·30	·11
Determination of moisture,* .	23·13	24·71	33·11	32·41	31·11

* The figures given represent the quantities present in 100 parts by weight of wood.

The creosoting of the deal blocks, therefore, does not appear to reduce their absorption of sewage.

An undesirable effect is often observed in connection with the use of creosoted blocks, namely, the gradual exudation of bituminous matter, which is forced to the surface and forms a thick layer, and which in hot weather is very objectionable to both horse and pedestrian traffic.

The two distinctive features which have, no doubt, largely influenced authorities in selecting deal for paving purposes have been its comparative quietness under traffic and the lowness of the initial cost, though this latter is somewhat modified when it is remembered that, at anyrate in London, the paving contractor is granted a maintenance allowance varying from 6d. to 1s. 3d. per yard per annum over the whole area laid.

The effect of creosoting is also to lessen the amount of expansion in comparison with the untreated blocks, as shown in the following figures (Table XLVII.), which were obtained by Mr. Buckham, Borough Engineer of Ipswich, from the immersion in water for forty-eight hours of six samples, three treated and three untreated.

TABLE XLVII.

	Creosoted.	Untreated.
On length of block, ...	·099	·6
On width ,, ...	·57	·83
On depth ,, ...	·15	·31

These results would represent in a 30-feet carriageway 2·72 inches for plain blocks, if under the same conditions. Compared with the West Australian hardwoods, Jarrah and Karri, creosoted deal shows slightly less expansion than the former, but considerably more than the latter.

In experiments carried out by Mr. H. T. Wakelam, County Engineer of Middlesex, in which he subjected several samples of Jarrah and creosoted deal to severe tests, he found that the comparative expansion, contraction, and absorption were as follows:—

TABLE XLVIII.

	Expansion.	Contraction.	Absorption.
Jarrah, ...	1·37	6·94	6·60
Creosoted deal, . .	1·53	3·03	5·66

Mr. P. H. Palmer, the Borough Surveyor of Hastings, remarks upon deal paving, that "even when creosoted, owing to its coarseness of grain it takes up and holds a large amount of impurity due to the traffic and manure of the road. It is a difficult material to deal with in respect of expansion and contraction, and on the whole, whether creosoted or not, is much less sanitary than a hardwood paving. With regard to the life of softwood paving, this appears to vary very considerably in different places. There are instances where softwood appears to have only lasted for seven years or more, and others where it has lasted for seven to twelve and fourteen years. This, of course, may be due to a combination of circumstances, such as the nature of the traffic, width of the roadway, and principally to the careful selection and laying of the blocks."

The point of selection of blocks is an important one in connection with every description of wood employed for paving purposes. It should be free from sap, close and evenly grained, and thoroughly well seasoned.

There is a somewhat wide difference of opinion in regard to the wear of softwood, some authorities asserting that it wears down more evenly than hardwood, while, on the other hand, there are those who contend that it is very liable to wear into holes, allowing water to collect, which naturally has the effect of inducing decay. On the other hand, one of the London borough engineers, who is a large user of hardwood, states that softwood wears more evenly than the former.

The following Table (No. XLIX., page 373), compiled from figures obtained by the Borough Engineer of Camberwell and others, shows the cost and estimate of the wear of softwoods in the London boroughs and certain provincial towns.

From these figures it will be seen that there are considerable differences in the matter of cost, of the estimated life of the wood—a factor which is so largely governed by the locality and amount and description of traffic passing over the roadway, and of the cost of taking up old blocks and relaying new on existing foundations.

TABLE XLIX.

	Cost per yard super. with foundations.	Estimated life of wood.	Cost of taking up and relaying new blocks.
	s. *d.*	Years.	*s.* *d.*
LONDON—			
Battersea,	13 3	10	...
Camberwell,	15 0	7	12 3
Hammersmith,	11 6	...	8 0
Marylebone,	10 0	7-10	10 0
Paddington,	12 6	15	7 8
Shoreditch,	12 6	5	...
Westminster,	10 0 to 12 0	8	...
Brighton,	11 10 to 14 8	...	...
Bournemouth,	11 0	10	...
Cardiff,	12 6	14	...
Hull,	6 6 (without foundations)	10	3 6
Plymouth,	12 0	11	8 0
Wolverhampton,	15 9	8	12 9
Birmingham,	13 0	10	...
Bristol,	11 0	10	...

During the year 1906 objections were raised against the use of creosoted deal blocks on account of the fumes given off by the creosote oil. The roadway round Parliament Square had been newly laid with these blocks, and a subsequent observation showed that the flowers planted in the plots adjacent to the roadway had become strangely affected, in that the blossoms had fallen off and the leaves had shrivelled. Such an occurrence had not before been noticed, and it was attributed to the effects of the creosote oil. A similar experience was also recorded at Bristol in the grounds of a florist, whose plants had suffered in the same way. As no experimental proof has been obtained of this peculiarity, it cannot be said decidedly that the withering of the flowers was entirely due to the cause referred to. In both cases, independent of one another, however, the effects produced followed immediately on the laying of the creosoted deal.

406. Hardwoods.—The woods now in general use for paving are the West Australian hardwoods, Jarrah and Karri, and Blackbutt, a New South Wales wood. The West Australian woods are by far the most widely used. All the woods belong to the Eucalyptus family, and their tensile and crushing strengths are high. The average weights of Jarrah and Karri are respectively 65 lbs. and 63 lbs. per cubic foot, as compared with 54 lbs. for British oak and 40 lbs. for elm. The principal properties of the West Australian woods are as follows:—Karri (*Eucalyptus diversicolor*) is a hard, heavy, pale red wood, with very little absorptive power; the fibres are strongly interlaced, and it is of great tensile strength. It contains tannin and other gum resins. Jarrah (*Eucalyptus marginata*) is a heavy, hard wood, slightly redder in colour than Karri. It has very little absorptive power, and is very durable and tenacious. It is consequently an excellent wood for paving. It also has considerable natural antiseptic properties, containing a red resin (red kino), 4 to 5 per cent. of kino-tannin, and a vegetable acid, viz., oxalic, which is particularly disagreeable to the various forms of insects (ants, wood beetles, etc.) which generally infest woods, and this property alone renders it very valuable. Both these woods are, as stated, red in colour, and a common method of distinguishing them from one another is by burning, Jarrah leaving a black cinder and Karri a light-coloured ash. There is also the specific gravity test, Jarrah weighing 2 lbs. more to the cubic foot than Karri.

Blackbutt, a New South Wales hardwood, has been to some extent employed in this country, but not sufficiently to enable an opinion to be given as to its suitability for paving purposes. Among the towns which have had this wood laid down are Edinburgh, Newcastle, Newport (Mon.), Leith, etc., where they appear to have given satisfaction as a paving material.

The paving in Newcastle was down seven years and showed no signs of wear. The recorded dry weight of the wood is 46 lbs. to 59¼ lbs. per cubic foot, and the grain is coarse and dense. It is also said to be non-inflammable. The absorptive power of the wood is about 2 per cent., while the expansion and contraction are said to be very slight. It is, however, a wood of even closer texture than Karri, and would, therefore, be more slippery and give less hold for horses than the West Australian woods, especially where the gradient is steep. Mr. R. W. Richards, late City Surveyor of Sydney, N.S.W., states that during 1888 wood pavement was laid in Castlereagh Street, between Park and Bathurst streets, with a close joint. The paving material consisted chiefly of Blackbutt and Tallow wood, and during the week ending 27th February 1904 blocks were removed from portions of the carriageway carrying the most of the traffic which may be taken as heavy and continual, and upon examination showed an average wear at the rate of $\frac{1}{30}$th of an inch per annum. Blocks of Blackbutt and Hardwood removed from Kent Street, subjected to the heaviest class of traffic common to mercantile and wharf districts of the city for twelve years, showed wear at the rate of $\frac{1}{30}$th of an inch per annum. The loss in wear annually of these woods at Sydney being so slight would no doubt arise from the fact that the surface is treated once or twice each year with a dressing of distilled tar and sand.

407. In addition to the hardwoods mentioned, several other descriptions have been introduced from different countries, but none have made any headway for paving purposes. Among those experimented with are tallow-wood, blue gum, red gum, Algarrobo, camphor-wood, stringy-bark, etc.; that which caused the greatest stir in paving circles was the wood known as American Red Gum. Excellent as this wood has proved for other uses, its adoption in this country showed that it was entirely unfitted for paving purposes. It was first laid in Whitehall, in 1901, and at the end of a year's wear had to be partially relaid, and was subsequently replaced by creosoted deal. During the few years it was down repairs and relayings were constant, and the same experience was recorded at Kensington and Brighton, and other places where it has been adopted.

The other woods mentioned have neither been tested for a sufficient length of time nor extensively enough to warrant any conclusion being arrived at in regard to their suitability as a paving material or as to their wearing qualities.

408. When the West Australian hardwoods were first introduced into this country in 1888 there was great difficulty in obtaining thoroughly seasoned timber, and this acted detrimentally against its adoption and produced erroneous opinions as to its advantages as a paving material. The contraction and expansion were excessive, and, on account of its too unseasoned state, the wear was far from satisfactory. When, however, this defect was removed and well-seasoned blocks were supplied, these hardwoods took the place among paving materials which experience has proved that they should occupy. The chief characteristics of these woods for this purpose, in comparison with other materials, are exhibited in the following Table (L.), which was specially drawn up for a report on the subject by the Agent-General for Western Australia:—

TABLE L.

	First.	Second.	Third.
Durability, . . .	Hardwood.	Asphalt.	Softwood.
Economy, . . .	Hardwood.	Asphalt.	Softwood.
Hygiene, . . .	Asphalt.	Hardwood.	Softwood.
Quietness, . . .	Softwood.	Hardwood.	Asphalt.
Safety, ...	Wood.	Asphalt.	
Traction resistance, .	Asphalt.	Wood.	
Ease of cleansing, . .	Asphalt.	Hardwood.	Softwood.
Ease of repair, . .	Asphalt.	Wood.	

409. Gradients.—The steepest gradient which could be successfully laid with wood paving was considered to be 1 in 40. Streets having steeper gradients are now paved with wood, as, for instance, Savoy Street and Arundel Street in London, which are situated on gradients of 1 in 12 and 1 in 14 respectively. It is, however, considered in modern practice that streets should not be paved with wood where the gradient exceeds 1 in 27. Under certain atmospheric conditions the paving becomes slippery, and requires sand or fine gravel sprinkled over the surface to ensure a good foothold. The frequency with which this has to be done increases as the gradient becomes steeper, and the expenditure under this head, in giving an artificial foothold, amounts to a considerable sum annually.

410. Contour.—The convexity adopted for a wood pavement is generally $\frac{1}{60}$th to $\frac{1}{80}$th of the width of the carriageway, and may be made in form of a segment of a circle, or according to the ordinates shown in fig. 133.

411. Foundations.—Upon the excellence of the foundations of all high-class pavements depends to a very large extent their wear and the retention of an even surface. In fact, too much attention cannot be given to this matter, for many of the defects which have appeared, especially in wood pavements, are attributable to the inferior material and work which have been put into the foundation. It is a matter of experience that many otherwise good carriageways have been rendered unfit for traffic on account of the sinking of the wood blocks and the consequent greatly accelerated wear on the surrounding paving material, whereas if the surface paving had been laid on a thoroughly consolidated concrete base, the roadway would have lasted for years; therefore too much stress cannot be laid on this point.

Experience has shown that the best foundation is one composed of cement concrete, and the more perfectly it is laid the longer the life of the paving above it. But under the concrete roadway is another foundation, one of earth, which has frequently been disturbed for a considerable distance, and which, if not properly consolidated, will render all care afterwards of little avail; for the traffic follows the completed street so quickly that depressions must occur if this is not very well done, as the concrete is not sufficiently hard to resist the pressure. The foundation of concrete is the real roadway, and it should be perfect in form and as strong to resist compression as it can be made with good Portland cement concrete.

For wood paving it is imperative that the exact falls required should be given to the surface of concrete. It should be even and true, and although not required to withstand wear and tear, should be impermeable to moisture. Wood blocks are cut to an exact gauge and laid upon the concrete without any intermediate padding; therefore the under level rules the upper. For asphalt and granite paving these conditions are not so important. The asphalt can vary a little in thickness, and its perfect form depends on the skill of the workmen laying it more than on the surface of the concrete underneath, while the granite blocks vary so much in depth that they have to be laid on a bed of sand of sufficient thickness to adjust their inequalities.

The compressive strength of concrete is very great when it is allowed time to mature and harden, say seven days as a minimum. Proportions of 6 of clean gravel to 1 of Portland cement when hard will bear a pressure of 100 tons to the square foot; 8 to 1, 75 tons; 10 to 1, 50 tons; and 12 to 1, about 33 tons per square foot.

Concrete is very weak in tension, being only about $\frac{1}{10}$th of its compressive strength, a fact which shows how necessary it is to have the ground well consolidated on which the concrete is laid. Engineers and surveyors should bear this in mind, and should specify that small steel rods, with their ends turned up, should be placed as low in the concrete as possible, across the site of the trenches recently cut and filled. Steel has a tensile strength of 62,720 lbs. per square inch, and by placing these bars low down, and of a shape that cannot slip, we can make up for the deficiency in the tensile strength of the concrete, and make the lower half nearly equal in strength to the upper.

Chalk and river mud are the constituents of the Portland cement made on the Thames and Medway. An excess of the former is very likely to produce a cement containing caustic lime; and an excess of the latter either causes fusing in the burning, which makes the clinker useless for cement, or it is under-burnt and produces an inferior article. It is the clay that possesses the power of rendering the compound hydraulic.

The strength of the concrete depends very much on the quality of the aggregate. It should be clean, angular, and hard, and of all sizes from $\frac{1}{8}$th of the thickness of the foundation to the finest grains of sand. Gravel, broken stone, igneous rocks, flints, sandstones, limestones, broken bricks, burnt clay, coke breeze, slag, are all used.

On the point of the setting qualities of a cement, Mr. H. K. G. Bamber, the managing director of the Associated Portland Cement Manufacturing Co., Ltd., stated in a paper he read some time ago that the cement supplied by a manufacturer to a required setting time may vary considerably in its setting characteristics, in accordance with the amount of aeration to which the sample is subjected, and that this unavoidable variation, due to atmospheric causes, is a fruitful source of trade disputes. The cement should, as far as possible, be tested as received.

The method of testing the setting time most in favour is that of the use of a weighted "needle," having a point $\frac{1}{16}$th of an inch square, and weighing in all 2½ lbs. The cement is not considered set so long as an appreciable impression is made when the needle is carefully applied to the surface of the pat.

In gauging the pat for this test, sufficient water should be used to produce a plastic mass, but care must be taken not to use an excess of water, which would result in a scum on the surface of the pat which would make observation of the real impressions difficult, and lead to divergent results.

Many cements, especially those of a slow setting character, will continue to show faint impressions upon application of the needle long after the actual "setting" has taken place, which will continue until superficial hardening of the pat prevents any further marking.

In cements of this description, experience only can guide one in fixing the point when setting is complete and hardening in progress.

The temperature and humidity of the surrounding atmosphere also plays a not inconsiderable part in the action of the setting of cement. A hot dry atmosphere will tend to more rapid setting. As far as possible a normal temperature of 62° Fahr. and a moist atmosphere should be maintained in the laboratory. Pats should always be made on glass or some other non-absorbent material, and kept in such position that undue evaporation of the gauging water is prevented.

Very slow-setting cements frequently show contraction cracks while setting from this cause, the water being evaporated before the chemical action by crystallisation is complete, with consequent shrinkage. There is no difficulty, however, in distinguishing between a contraction and an expansion crack. The former, however, is frequently taken for the latter, causing much consternation and unnecessary trouble and anxiety to the consumer, and annoyance to the manufacturer, who, having supplied what has been required of him, cannot control the forces of nature. In testing slow-setting cements for setting time, it is always advisable to take special precautions against evaporation; the pats when gauged should be covered, or placed in some receptacle in which the atmosphere can be kept moist until the setting is complete.

In most cases the old foundation of concrete, which has done service for other descriptions of paving material, is utilized, with the addition of being floated with cement mortar to render the surface smooth, and make good any depression or alteration of the contour which the finished surface of the street is to assume when completed. This is accomplished by fixing level-pegs longitudinally and transversely to secure efficient surface drainage. The intermediate points are determined by means of boning-rods, and the carriageway is then divided into panels or bays of a certain width for carrying on the operations of floating the surface with cement mortar. Iron wedges are driven into the concrete foundation at intervals of 5 or 6 feet across the roadway between the kerbs or channels, and wooden pegs inserted into the holes thus made; the height of each is fixed by boning; the tops of the pegs are then cut off, where necessary, to the proper level. On the top of these a lath 2½ inches by ¾ inch is fixed by nails forming a template, the upper side of which corresponds to the finished surface and the required contour of the cement mortar coating. The panels may vary from 12 to 15 feet in width, and each alternate one is completed and allowed to set before commencing the others. The cement mortar or rendering is regulated by means of a straight edge, worked between the lath-templates transversely, which ensures the surface being finished in a uniform manner. When the whole has become hard, the laths are removed and the spaces filled in with thick cement grout.

Expansion of the concrete foundation has to be considered, and it is now usual to provide an expansion joint 1 inch wide across the roadway at about every 100 feet. In wide streets it also becomes necessary to provide one or two longitudinal expansive joints placed a few feet from the kerb. These joints are generally filled with plasterer's putty.

As there is no cushion of sand made use of in wood paving, at all events in first-class work, it is absolutely necessary that the concrete should be thoroughly hard before commencing to lay the paving blocks. The time necessary for this will, to a certain extent, depend on the weather, but is usually from ten to twelve days; in many cases, however, the laying of the blocks may be commenced six days after the completion of the concrete foundation. The surface should be swept clean and be thoroughly dry before the blocks are laid upon it and grouted.

412. Method of Laying.—Too much stress cannot be laid on the point that all wood blocks must be thoroughly seasoned and carefully selected before being laid; and where facilities permit, the stocking of blocks a certain time previous to laying is not by any means a bad method to adopt. In some boroughs and towns machinery is provided for cutting the blocks from the hardwood planks, and is found to be more economical than obtaining the paving blocks in a finished state. It is, however, absolutely essential that they should be cut perfectly true, to admit of close jointing.

The general practice in regard to hardwood paving is to use blocks measuring 9 inches long, 3 or 4 inches wide, and 5 inches deep. In some instances, however, the depth has been reduced to 4 inches; and considering the specific gravity and other qualities of the wood, there does not appear much justification for adopting a depth of 5 inches. If blocks of this latter depth are used, however, it is possible that when the surface has become considerably worn and requires repair, the blocks may be taken up, trimmed down to 3½ or 3 inches and relaid, as has been done at Camberwell and elsewhere. Another instance of using shallow blocks is that of the New Kent Road, where Jarrah blocks, 6 × 3 × 3½ inches, have been laid and are proving very satisfactory. Hampstead also has several miles of 4-inch blocks, as also has Bethnal Green and a number of provincial towns. This movement in the direction of using shallow blocks is one that has originated during the last few years, and is well worth the consideration of engineers and surveyors, though it has been asserted that in consequence of the concrete foundation being brought nearer to the surface, the heat of the sun would affect this, and by radiation cause expansion of the blocks.

The custom universally adopted in laying the blocks is, transversely across the street with the fibre of the wood vertical and immediately on the concrete foundation, though a layer of sand from ½ to ¾ inch deep is sometimes introduced between the paving and the foundation.

The latter system is adopted with a view to reversing the blocks when they have become uneven through wear, and the sand cushion also tends to reduce noise. This arrangement, by which the life of the pavement is prolonged, can only be advantageously adopted in streets which have moderate traffic. The making of the joint is performed in various ways, the material used being either cement grout or a bituminous composition. The wide joint which was characteristic of this class of pavement some years ago has, in most recent work of this description, been practically eliminated. It is generally admitted that wide joints on a level, or comparatively level, carriageway do not afford foothold for horses more than paving laid with close joints. On gradients, however, it is usual to set the blocks with a ¼-inch or ⅜-inch joint for the safety of horse traffic. Fig. 137 shows a cross-section of a wood pavement.

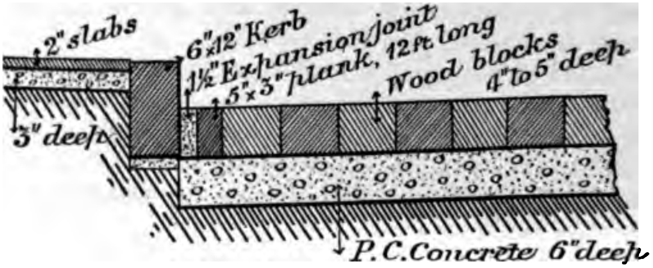

FIG. 137.—Cross-section of wood pavement.

413. In connection with this question of laying wood blocks, there have been methods introduced having as their object the bonding of the separate blocks together, and although this has its advantages in the direction of reducing vibration and the consequent displacement of the blocks, it adds to the cost of the paving, and has, in consequence, not been very largely adopted by municipal authorities, though it is stated that blocks of less depth may be used if they are bonded together in such a manner.

The system chiefly in vogue for this purpose is that known as Duffy's Dowelling System. Under this method a perfect bond is secured between the individual blocks themselves, while it ensures the adhesion of the block to the foundation upon which it is laid. These advantages are obtained by the dowelling of the blocks, which is briefly as follows:—Into the concrete foundation covered with a floating of cement are built a series of what are termed "bonding blocks," the top of these blocks being level with the cement. When the latter is thoroughly dry and hard the blocks are laid thereon, each separate block being secured individually together by means of dowels fitting into corresponding recesses in the adjacent blocks. By this means a union or "Bond" of the greatest strength and tenacity is effected, the blocks being held firmly in position at every point.

414. Method of Forming the Joints.—A considerable difference of opinion exists as to the most effective form of jointing for wood paving—many advocating close joints, that is, butting the blocks together so closely as to get a continuous and unbroken surface; while, on the other hand, there are those who consider blocks should be laid with ⅛-inch to ¼-inch open joints. One authority states that blocks should be laid as closely together as possible, consistent with the fact that sufficient space is allowed to ensure that the ⅛-inch pitch or cement grouting thoroughly penetrates the joints all round the blocks, thus providing a water-tight surface. This close jointing necessitates very precise cutting of the blocks, otherwise they would have a tendency to rock.

In a paper read by Mr. W. N. Blair on the jointing of wood pavements before the Incorporated Association of Municipal and County Engineers, 1893–94, he remarked that he had laid roads varying from 22 feet to 48 feet in width, with yellow deal, pitch, pine, Jarrah and Karri, with ⅛-inch and ⅒-inch joints, regulated by a lath of that thickness and 1 inch wide laid on edge in the bottom of the joint and left there, the cross joints being left open the same width, but without the lath. The channel joints have been made from ¾ of an inch to 1½ inch, and the whole of these filled with a hot compound of pitch and creosote oil, proportioned suitably to obtain a freely ductile mixture at a temperature of about 60°, the proportions being usually 1 cwt. of pitch to 1½ to 2 gallons of oil, some variation being necessary to meet the differences in quality of the pitch. This compound is poured over the paving out of a bucket, and a rubber squeegee is used to push forward the fluid, so that as little as possible remains on the surface. In all work done in this way no case occurred of any pressure being exerted on the kerbs. It is now, however, recognised that an open joint greatly reduces the life of the wood, the fibre being allowed to spread and disintegration following, while at the same time it is of little or no advantage in the way of providing a better foothold for horses. Moreover, joints foster dirt, and dirt causes danger to traffic, while it must have injurious effects on the blocks themselves.

Nearly every engineer, however, has his own method of effecting this work: at Camberwell the practice is to lay the blocks closely jointed, and grouted with cement, the blocks being previously dipped in a mixture of tar and pitch; at Hammersmith the borough engineer adopts a grouting of pitch and oil; while at Hampstead the blocks are laid in pitch and creosote oil to within ¾ inch of the surface, the remaining depth being filled with Portland cement grout. Pitch and oil and prepared tar are also adopted for this purpose in other London boroughs.

When the joints are to be grouted with Portland cement or bituminous grout, a certain space between the blocks is imperative. A joint ⅛ inch to ⅜ inch, according to the conditions, is required, for which provision is made by inserting a wooden lath about 1 inch deep laid on edge at the bottom of the joint and left there. These wooden strips or laths, besides providing for the necessary width of joint, maintain the regularity of the joints, and they are in some instances placed at the top of the blocks and removed when the joints are filled. The cross joints are likewise left open, but without the lath.

The bituminous grout, composed of pitch and creosote oil in a proportion of 1 cwt. of pitch to 1½ to 2 gallons of oil, according to the quality of the pitch, is then poured over the pavement by means of a bucket, the joints being filled by brushing the fluid into them or by using a rubber squeegee, which pushes the liquid over the surface, fills the joints, and leaves as little of the grouting mixture on the surface of the carriageway as possible.

The composite joint, such as is used at Hampstead, is formed by pouring the bituminous composition into the joints so as to fill the lower portion of them to a depth of 2 inches; the remaining or upper portions of the joints are then grouted with Portland cement mortar, composed of 1 of cement to 3 of clean, sharp sand.

The close joints of a wood pavement grouted with pitch are of an elastic nature, which admits of their yielding to the expansion of the wood, thus preventing lateral pressure being transmitted to the channels or kerbs, and ensuring that the arrises of the blocks do not become worn and rounded. This latter defect, inseparable from a pavement laid with wide joints, produces a corrugated or corduroy surface, making the pavement noisy and dirty, and reducing its life considerably.

Portland cement grout requires at least ¼ inch space between the rows to form a joint, and, being of a rigid nature, is not capable of yielding to local expansion of the wood blocks; hence under certain circumstances the pressure is transmitted to the channels, and may displace the kerbstones in the manner mentioned. The vibration created by heavy wheel traffic at times loosens the blocks of a wood pavement which has been jointed with cement grout, thus destroying its imperviousness.

There is one distinct property which characterizes a pavement grouted with cement, and that is, it can be executed in any weather, except during frost, which is an advantage towards facilitating the progress of the work; on the other hand, it requires at least six days to properly set, which is a great disadvantage in most cases.

Cement grouting makes a wood pavement much more noisy than one formed with a pitch composition which is of a slightly elastic nature. The arrises of the blocks, especially in wide-jointed pavements, becoming worn or rounded, the cement filling is exposed, which soon becomes disintegrated by the action of the horses' feet.

When pitch grout is adopted as the material for forming the joints, the blocks can be laid practically close or with a space not exceeding $\frac{1}{10}$ inch in width, which, besides making an impervious and more durable pavement, prevents the spreading of the fibre of the wood, and admits of a smooth surface being retained; while the facility for cleansing the pavement is greatly increased.

The bituminous composition, being of a slightly elastic nature, absorbs and equalizes the expansion of the blocks; it also acts as a preservative to the wood. One disadvantage, of which mention has been already made, is that the joints must be made only when the wood is thoroughly dry, wet weather being detrimental to its use. Under these circumstances it is usual to cover over the pavement with tarpaulins. As the bituminous grout hardens almost immediately after the joints are filled, traffic may be allowed to pass over the pavement on the completion of the work. Special travelling boilers are generally employed for preparing the pitch and creosote oil composition; the mixture, when of a proper consistency and in a boiling state, is drawn off in suitable buckets, or into wheeled carriers transported to the pavement under construction, and poured into the joints. As volatilization takes place in pitch joints, and consequently disintegration in hot, dry weather, the filling to prevent this defect is generally made of pitch in the lower part of the joint, and finished with Portland cement grout.

The merits and demerits of close and wide joints, from a maintenance and sanitary point of view, and as affording a good foothold for horses, was investigated many years ago, and the conclusions then arrived at are the principles governing the present methods of paving work.

415. Wear of Wood-Paving.—With the large experience which has now been obtained with wood-paving, it should not be difficult to arrive, at any rate, at an approximate figure in regard to the life of a carriageway. There are, however, so many influencing factors in the matter, that no definite calculation could be made to provide a certain answer, were it possible to obtain exactly identical conditions in connection with every description of wood used—that is to say, if one could rely on the foundation of the roadway being as efficiently composed and laid, the surface material in equally good condition, the climatic influences the same, and the traffic, both in extent, kind, and weight, precisely similar, then some finality might be reached on the subject. In every town where wood-paving is laid there exist considerable differences in practising all of these items. Under these varying circumstances, therefore, comparative figures may be accepted on this point, and, if looked at in the light of local requirements, an approximately reliable conclusion can be reached.

The Table given on page 375, in which the various qualities of paving materials are dealt with, may be taken as a general basis for ascertaining this point, which, however, will be modified by individual experiences. The divergences found in such instances are illustrated in the following Tables (LI., LII., and LIII.), which have been compiled from official figures:—

TABLE LI.

Hardwoods.

	Years.	PROVINCIAL—	Years.
LONDON—		Birmingham,	15
Bermondsey,	10	Edinburgh,	15
Camberwell,	10	Glasgow,	7
Hammersmith,	11	Huddersfield,	15
Holborn,	8-10	Hull,	12
Paddington,	9	Plymouth,	18
St. Pancras,	7-8	South Shields,	15-18
Shoreditch,	8	Wolverhampton,	10

The actual wear which has taken place in the West Australian hardwoods in London and certain provincial towns is shown in the following figures, which have been collected from various authoritative reports:—

TABLE LII.

LONDON—	Years laid.	Wear in inches.	PROVINCIAL—*continued.*	Years laid.	Wear in inches.
Camberwell,	5	$\frac{5}{8}$	Bristol,	6	$\frac{3}{8}$
Hammersmith,	9	$1\frac{1}{2}$	Cardiff,	4	$\frac{3}{32}$
Hampstead,	7	$\frac{5}{8}$	Harrogate,	6	$\frac{1}{8}$
Lambeth,	$10\frac{1}{2}$	$1\frac{1}{8}$	Hastings,	6	$\frac{1}{8}$
Southwark,	7	1	Hull,	6	$\frac{1}{4}$
PROVINCIAL—			Leicester,	9	$\frac{1}{2}$
Batley,	6	$\frac{1}{32}$	Liverpool,	$5\frac{1}{2}$	$\frac{1}{3}\frac{3}{8}$
Birmingham,	$2\frac{1}{2}$	$\frac{1}{16}$	Sheffield,	8	$\frac{1}{2}$

The testimony of the Viagraph, as a result of tests carried out by the author in different London streets, may be introduced here. More detailed information, however, is given on this particular subject in Chapter XVII. The instances selected are those which give the nearest approach to identical conditions.

TABLE LIII.

Karri and Jarrah.	Index of unevenness in feet per mile. Slider.	 Wheel.	Traffic.
St. John's Road, Battersea, laid 1897,	(K.) 11·6 (J.) 8·0	21·0 17·0	Heavy and continuous.
Blackfriars Road, laid 1899,	15·8	19·7	Do.
Creosoted Deal.			
Battersea Park Road, laid 1895,	58·1	63·8	Do.
Kennington Park Road, laid 1898,	42·0	56·7	Do.

416. The undue wear of wood pavements is due to various causes, the majority of which may be averted by proper and efficient methods being adopted. In many cases the abnormal wear of the surface paving is attributable to the foundation, either by inferior materials being used, or by not allowing the concrete to get thoroughly set before the blocks are laid upon it.

Numerous instances of the latter defect have occurred in London, and it has been observed when the blocks have been removed that the concrete has been squeezed up the joints by the pressure of the traffic, consequently the blocks have sunk considerably below the original line, and, being subjected to unusual wear, have soon become unfit to remain, owing to their having become dangerous to traffic. Great stress has been laid, in a previous section of this chapter, on the importance of foundations, and in many cases it is the deciding factor in the life of a roadway. The materials employed must be of the best, and the method of laying, and the time allowed for thorough consolidation and setting, have so essential a bearing on the life of the surface paving, that too much care and consideration cannot be given to the matter.

The wear of the paving is also dependent on an efficient selection of the wood. The City Engineer of Birmingham adopts the plan of stacking the blocks for two months, so as to allow them to get thoroughly air-dried before being laid. This obviates the possibility of young unseasoned wood being embodied in the roadway, and defects of grain should also be looked out for. For maintaining an even surface, such methods as that of Duffy's dowelling are adopted. This gives a certain rigidity to the paving, and checks the vibration of the traffic, which frequently produces an undulating surface and partly increases the wear.

The subsequent treatment of the roadway has also a considerable effect on its life. In dry weather a moderate amount of watering should be indulged in, in order that the blocks should not become too dry, while in wet weather thorough cleansing should be carried out, and all horse droppings and other detritus removed.

417. In many boroughs and towns the wood paving, after being laid, is brushed over with hot tar and granite chippings, or broken shell is scattered over it. This forms a hard protective surface, and has been found to considerably increase the life of the paving. Mr. Oxtoby, the Borough Engineer of Camberwell, who has treated a considerable area with hot tar and broken shell, states that the cost of this is 1·16d. per yard superficial, and that not only is the surface of the roadway rendered more durable, but that defective joints are thereby re-grouted, preventing any quantity of moisture from percolating to the foundations, and, at the same time, rendering the whole surface almost impervious to offensive moistures, which under the action of the sun render wood paving objectionable from a sanitary point of view.

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TABLE

NAME OF TOWN.	Description of wood.	Test cost per square yard.		Nature of foundation.
		With foundations.	Without foundations.	
LONDON—		s. d.	s. d.	
Battersea, . . .	C. D.	..	9 0	9 in. P. c. concrete and floated.
,, . . .	K.	..	13 6	do. do. do.
Camberwell, . .	J.	15 0	12 6	6 in. do. do.
,, . . .	C. D.	15 0	12 3	do. do. do.
Fulham, . . .	C. D.	11 8	8 2	9 in. do. 1 in. do.
Hammersmith, . .	C. D.	12 10	..	7½ in. do. ½ in. do.
,, . .	J.	15 6	..	5½ in. do. do.
Hampstead, . .	C. D.	10 3	..	6 in. do. 1 in. do.
,, . .	J.	12 11	..	do. do. do.
Holborn, . . .	J.	14 3	..	Existing found.: 3 in. do.
City of London, . .	C. D.	10 6	8 0	6 in. P. c. concrete 1 in. do.
,, . .	J.	14 11	12 5	do. do. do.
St. Marylebone, . .	C. D.	..	6 10½	4 to 10 in. do. 1 to 3 in. do.
St. Pancras, . .	J.	14 3	11 6	6 in. do.
Shoreditch, . . .	J.	16 0	..	do. do. ¾ in. do.
Stoke Newington, .	C. D.	..	6 0	Existing found.
Wandsworth, . .	C. D.	11 8	7 8	6 in. P. c. concrete 1 in. do.
City of Westminster, .	C. D.	10 4	7 7	do. do. 1 in. do.
PROVINCES—				
Bath, ...	J. and K.	12 6	..	6 to 9 in. do.
Birmingham, . .	J. and K.	15 6	..	.. ..
	C. D.	13 0	..	.. ..
Blackpool, . . .	J. and K.	12 0	..	5 in. do. do.
Cardiff, . . .	J.	16 6	..	6 in. cement concrete, 6 to 1.
Hastings, . . .	J.	14 0	..	6 to 8 in. do.
Hull, ...	J. and K.	16 0	7s. 9d.-9s. 4d.	7 in. do.
Newcastle, . . .	J. and K.	16 6	..	6 to 7 in. concrete with ½ in. sand on surface.
Plymouth, . . .	J.	16 0	..	6 in. concrete.
	C. D.	12 6		
Ramsgate, . . .	J.	14 6	..	do. do. (8 to 1).
	C. D.	11 9		
Sheffield, . . .	J. and K.	14 3	..	.. ..
Wolverhampton, .	J.	16 8	..	do. do. (6 to 1).

C. D. = creosoted deal; J. = Jarrah;

418. In the latest report prepared by Mr. W. N. Blair, Borough Engineer of St. Pancras, dealing with hard and soft woods for paving, and summarizing replies he received from various boroughs on the subject, he says: "With regard to the benefit of creosoting, a few of the answers received state definitely that it does add to the life of the wood, while others state that it does add to the life of the wood where light traffic is concerned, but under heavy traffic it is questionable whether it does prolong the life. The explanation of this is, that, where the life depends upon the amount of wear due to the traffic, it is doubtful whether creosoting extends that life." Comparing hardwoods and softwoods, he says that "Deal paving wears more evenly, but unquestionably it wears more quickly. It requires repair at a much earlier date than Jarrah blocks, and having once commenced to repair, the extent of repairs will

LIV.

Size of blocks.	Description of grouting, etc.	Annual cost of maintenance per square yard: (*a*) repairs; (*b*) cleansing and watering.		Estimated or actual life of wood paving under heavy traffic.	REMARKS.
Inches.		(*a*)	(*b*)		
..	.. ..	..	..	..	.. ..
6 to 9×5×3	Close jointed, pitch, etc.	..	..	..	Traffic considerable.
9×5×3	Dipped in pitch, etc.	..	..	9 years down, extending use.	Do. do.
9×5×3	Grouted with P. c.	..	..	..	.. ..
9×5×3	Pitch and cement.	..	..	15 years.	Do. do.
8×5×3	Pitch and oil.	..	..	May 1904.	Do. do.
9×5×3	Do.	..	..	Oct. ,,	Do. do.
8×5×3	Do.	..	..	July ,,	Do. do.
9×4×3	Do.	..	..		
9×5×3	.. ..	..	..	Sept. ,,	Do. do.
9×5×3	Pitch and oil.	10d.	..	May ,,	Do. limited.
9×5×3	Do.	1s.	..	Do.	Do. considerable.
6×3 deep	Dipped in pitch.	1s. 2d.	..	..	Do. do.
9×4×3	$\frac{1}{16}$ in. slip-in joints, grouted with hot pitch and oil.	..	..	Extending use of Jarrah.	Do. do.
9×5×3	Pitch.	..	..	1904.	Do. do.
8×4½×3	Do.	..	..	1905.	.. ..
8×5×3	Dipped, tar and P. c. grout.	..	..	1904.	Do. do.
9×5×3	Close, pitch and oil.	..	..	1904.	Do. do.
9×4-5×3	.. ..	..	..	15 years.	Do. do.
9×4×3 9×6×3	Close, pitch.	3d. 4d.	4d.	..	Do. do.
9×4½×3	,, cement and sand, same dipped in pitch.	..	..	..	.. ..
..	.. ..	..	..	..	.. ..
..	Close, bitumen.	..	4d. and 2d.	12 years.	Do. heaviest.
9×4½×3	Dipped in hot asphalt, close.	..	..	12 years.	.. ..
9×5×3	Close, dipped in pitch and tar.	..	..	12 years.	Heavy traffic.
9×4×3	Close, cement and sand.	..	5·53d. ·80d.	18 years. 15 years.	Laid in main streets.
9×4–5×3 9×5×3	Close, dipped in asphalt, then grouted with thin cement.	..	..	..	.. ..
9×5×3	Dipped in pitch and tar, cement and sand.	..	..	..	Do. do.
9×5×3	Close, pitch and tar.	..	..	10 years.	.. ..

K. = Karri; P. c. = Portland cement.

increase throughout the life of the wood." He instances the wear of Jarrah blocks in an area laid in St. Pancras in 1892, and upon which a very small sum had been spent in repairs. They are now being removed, though the blocks are not worn out, but the surface has become bumpy. This shows a wear of 14 years under heavy traffic, which time would, he says, have been increased had the repairs been more frequent. Mr. Blair summarizes this experience with both descriptions of woods, thus:—Jarrah, easily cleansed; very durable; good foothold generally; becomes noisy by wear on edges of blocks. Creosoted deal holds the dirt and becomes greasy; less secure foothold; takes frost readily, therefore slippery; wears evenly, but quickly; more silent under traffic; exudes an oily film, causing slipperiness and an unpleasant odour for some time. The effect of creosoting at first reduces porosity, but this protection diminishes.

419. Expansion and Contraction.—Every wood pavement is subject more or less to expansion and contraction, and, in order to obviate any injuries to the roadway, an expansion joint is usually introduced between the wood and the kerbs. The customary width of this joint is from 1½ to 2 inches on each side of a 60-foot roadway, though in some places 3 inches is allowed, and this is filled up with either a hot mixture of pitch and creosote oil, sand, or clay.

The general experience has been this, and is borne out by scientific investigations, that softwoods expand considerably more than hardwoods. In the nature of things it is apparent that the former would be far more subject to this action than the latter. They are more absorbent to liquid matters, though not so much affected by heat as hardwood, and it is on this point that greater attention has to be paid to the latter at that time than in the wet season. Hardwood blocks should be carefully watered in hot, dry weather, in order to counteract the tendency to expand and contract. If this is done, there should be little or no difficulty in maintaining a high-class roadway in excellent condition and increasing its life. The treatment of a roadway after it has been laid is a most important matter, and is a determining factor of greater moment than is generally considered. With hardwoods, it is more the variations in temperature that have to be watched than other agencies, while softwoods are affected more by general climatic influences, especially where moisture is the most prominent characteristic. The effects of creosoting, as has been pointed out by several authorities, are greatly minimized by the pavement being subjected to constant rain and the percolation of other liquids into the wood, which makes the blocks more amenable to expansion. Any method, therefore, which obviates this will increase the life and wearing power of the paving. There are processes which may be adopted towards this end, one of the most satisfactory at present being that known as powellizing, which is described in another part of this chapter. The treatment to which softwood blocks are subjected in this system is said to considerably reduce their tendency to expansion and contraction.

420. Cost of Wood Pavements.—The cost of laying a soft- or hardwood pavement depends on circumstances, the work being for the most part carried out by contract; only in a few instances is the timber bought at so much per load, cut by machinery into blocks of suitable size, and the work carried out by the local administration. The price of yellow deal cut into 3 x 5 x 9-inch blocks works out at about £7, 10s. per 1000 blocks, and for Jarrah and Karri at about £11 to £11, 10s. respectively, although the prices fluctuate considerably at times.

The cost per super. yard and other particulars of these woods may be ascertained from Table LIV. Their variations in price, of course, are due to the situation of the locality and to the quantities used. An estimate is given of the relative costs of a hardwood and softwood roadway, over a period of twenty-four years, in Table LV.

The comparative cost of hard- and soft-wood paving during their life may be given as follows, taking the wearing properties of the former at twelve years and the latter at eight years. For this comparison, 1 mile of carriageway 30 feet wide is adopted.

Table LV.

Hardwood. Twelve years' life during twenty-four years.

First cost. 1760 × 10 yards = 17,600 square yards of Jarrah paving blocks, 9 inches × 5 inches × 3 inches, including foundations, laying and jointing, at an average cost of 15s. 6d. per yard, ...	£13,640	
Contingencies, ...	500	£14,140
Second period of twelve years—		
Lifting old blocks, refloating concrete foundation, supplying and laying new blocks, 9 inches × 5 inches × 3 inches, jointing, etc., at 12s. 6d. per square yard, . . .	£11,000	
Contingencies, ...	800	11,800
		£25,940
Repayment and interest on foundations and paving—		
Foundations. Twenty-four years at 3¾ per cent., . . .	£1,340·73	
Paving. 1st period of twelve years, ...	2,803·13	
Do. 2nd ,, ,, ...	2,881·25	
		7,025·11
Total repayment of principal and interest, ...		£32,965·11

which sum represents an average annual cost of 1s. 6·72d. per square yard for twenty-four years.

Softwood. Eight years' life during twenty-four years.

First cost. 1760 × 10 = 17,600 square yards creosoted deal, 9 inches × 5 inches × 3 inches, unlaying foundations, laying and jointing, at an average cost of 12s., ...		£10,560	
Contingencies, ...		350	£10,910
Cost of relaying, succeeding eight years, lifting, refloating, providing and laying blocks, jointing, etc., at an average price of 9s. per square yard, .	£7,920		
Contingencies, ...	530	8,450	
Next eight years, ...		8,450	17,900
Repayment of principal and interest on foundations, twenty-four years' life, ...		£1,340·73	
Paving. 1st period of eight years, ...		1,395·54	
Do. 2nd ,, ,, ...		1,425·94	
Do. 3rd ,, ,, ...		1,425·94	
			5,588·15
Total repayment of principal and interest, ...			£33,398·15

which sum represents an average annual cost for repayment and interest, but exclusive of repairs, of 1s. 6·98d. per square yard for twenty-four years.

To this sum has to be added the average cost for repairs on this description of wood according to that of the initial cost, and, for the case under review, 8d. per square yard per annum would be a fair figure, so that the total annual cost would be 2s. 2·98d. per square yard during the twenty-four years.

Repairs on softwood paving are generally carried out under a maintenance clause in the contract, and obtained in many cases, while for the hardwood paving it does not usually exist. One instance, however, may be noticed where a contract price for maintenance is enforced, that being in the City of Westminster. The initial cost of this paving was at a comparatively low figure.

The London County Council grant a loan on hard- and soft-wood pavings for ten and five years respectively, according to the cost per annum during their life service, and under these conditions the annual cost would be 1s. 10·51d. as against 2s. 2·2d. for softwood per square yard.

In Camberwell, London, the figures for paving 1000 square yards with hardwood and creosoted deal, including repayment and interest, and allowing ten years' life for the former description of wood and five years' for the latter, is given at 1s. 9·7d. and 2s. 2·7d. average cost per square yard.

421. Preservation of Wood for Paving.—In addition to the process of creosoting, the chief preservative method used for paving blocks at the present time, there are a number of others which have been adopted on a small scale. In several instances these appear to have answered the purpose well, though they have not made much progress in being adopted for paving work. Among these are the Haskinizing process and the Jodelite, both of which have been used for the treatment of paving wood. The most recent introduction in this direction is the process known as the Powell, which appears to offer considerable advantages.

Powellized Wood Blocks.—This process is one which possesses many advantages for the treatment of all kinds of wood for paving purposes, especially softwoods. It consists in thoroughly impregnating the blocks with saccharine matter to which is added a strong antiseptic.

One great difficulty with wood paving is said to be remedied by this process, namely, the uneven wear which arises from imperfect selection or irregular seasoning, as the wood absorbs exactly the quantity of saccharine matter it requires, and is consequently made thoroughly homogeneous. The condition as to seasoning before treatment is also immaterial, as newly felled or partially seasoned timber yields itself readily to the process, and, in fact, the newer the wood the better the final result.

The treatment consists in immersing the blocks in a cold antiseptic saccharine solution in open tanks, the temperature being gradually raised to boiling point and maintained at this heat for a short period. The air and moisture during the boiling escape in the form of a series of bubbles and of steam respectively, and in the subsequent cooling of the solution, which occupies some hours, the wood absorbs the saccharine matter and is thoroughly permeated with it. The blocks are then removed and placed in a drying chamber for a few hours, after which they are ready for immediate use. The application of pressure and vacuum, which weakens the fibres of the wood, and which is inseparable from the creosoting method of treatment, is not employed in this process.

It is claimed that powellized wood paving blocks are thoroughly seasoned, that there is less absorption of liquid sewage, that contraction and expansion are minimized, and that the blocks are tougher and made more durable. Moreover, there is no offensive smell given off or exudation, consequently no deleterious effects are produced upon plants, horses, or human beings, while the slipperiness of the wood is reduced to a minimum. In addition, paving blocks treated by this process are incapable of supporting fungoid growth, so that they are not subject to decay or dry rot. Some woods which cannot readily be impregnated with creosote, and, if used in their natural state, rot from the underside, can be used for paving purposes with advantage, when powellized. A notable instance in this respect is spruce, which, from the length and silkiness of its fibre, forms an ideal paving; but, on account of the formation of its cells, it can only be creosoted under such pressure as to materially damage the wood and render the cost prohibitive.

The cost of powellizing is about the same as that of creosoting. Powellized paving blocks have been undergoing trial in London and elsewhere for between two and three years, the first section having been laid in Westminster, Kensington, Islington, Willesden, Hull, and Birmingham.

CHAPTER XII.

ASPHALT PAVEMENTS.

422. Rock Asphalt.—Asphalt pavements for carriageways were introduced into London in 1869, having been used in Paris as early as 1854, where their application became general in 1867.

The principal sources of supply of bituminous or asphaltic rock, which is a natural calcareous stone impregnated with bitumen or mineral pitch of a liver brown colour, are Val de Travers, in Switzerland; Seyssel and Lovagny (Haute-Savoie), in France; Limmer, in Hanover; and also some Sicilian mines. The Pitch Lake in Trinidad supplies the bitumen from which the best artificial asphalts are made.

The asphalt chiefly used for carriageway pavements in Europe is principally obtained from the first three localities. Compressed Trinidad asphalt pavements, although more or less a failure when first introduced into this country, have been laid in London and other towns to some extent. That they are well suited for withstanding ordinary wheel traffic and the climate appears to have been in a measure determined.

In Canada and the United States, Trinidad is practically the only asphalt employed in the principal cities and towns, over 40 million square yards having been laid, the length of carriageways so paved approximating 3000 miles.

The reason assigned for the early failure of Trinidad asphalt is that compressed rock asphalt is only made perfect as a pavement by continuous heavy traffic, and in the cases of failure experienced the thoroughfares were wide, with comparatively light traffic. In the case of compressed Trinidad asphalt the proper proportion to suit all conditions of traffic and climate were not so well understood as in the more recent examples of these pavements.

The rock when quarried is of a chocolate colour, fine in grain, thoroughly and evenly impregnated with bitumen, varying from 6 per cent. of bitumen and 94 per cent. of pure limestone to from 14 per cent. of bitumen to 86 per cent. of limestone.

The pieces of rock, weighing from a quarter to half a cwt. each, are put into an asphalt crusher, where they are broken to the size of walnuts; after passing through the crusher the asphalt is carried up by elevators to the disintegrator, which runs at a speed of 1800 revolutions to the minute, and is ground to a very fine powder. It is then boiled in specially made cauldrons, worked by agitators, with a certain proportion of bitumen (as flux), and when heated to a temperature of about 400° Fahr., a proportion of 10 per cent. to 20 per cent. of fine grit is added to make gritted mastic, and thoroughly incorporated with the asphalt by the rotary working of the agitators. It is then turned out into iron moulds and made into blocks, weighing half a cwt. each.

These blocks are then broken up into pieces, put into small cauldrons with just sufficient bitumen (as flux), and when properly heated the mastic asphalt is spread over the concrete surface and rubbed with fine sand by means of hand floats.

The ungritted mastic asphalt, supplied by the Limmer Asphalt Company, is composed of not less than 15 per cent. of bitumen and 85 per cent. of fine rock asphalt powder. The gritted mastic asphalt is composed of not less than 15 per cent. of bitumen and 75 per cent. of fine rock asphalt powder, with an addition of 10 per cent. of fine specially prepared grit. Gritted mastic asphalt, however, for flooring, etc., is composed of not less than 15 per cent. of bitumen and 65 per cent. of fine rock asphalt powder, with an addition of 20 per cent. of fine grit.

In the case of Trinidad asphalt, the crude bitumen obtained from the pitch lake is refined so as to eliminate the water and vegetable matter contained in it. This refined bitumen, which becomes hard when cool, is converted into "asphaltic cement," by adding a small quantity of residuum oil of petroleum, which gives the mixture a certain amount of plasticity. This, in combination with sand and powdered limestone, forms the asphaltic composition. The bitumen cements the other ingredients when mixed hot, the proportions being regulated according to the quality of the "asphaltic cement" and the character of the sand; if this is of a suitable nature, the limestone dust is dispensed with altogether. The climate of the particular locality in which the pavement is to be laid has also a considerable influence on the relative proportions of the ingredients in the mixture.

Generally the proportions may be taken as follows:—

Asphaltic cement, ...	14 to 17	per cent.
Sand, ...	81 to 68	,,
Stone dust, ...	5 to 15	,,
	100 100	,,

Compressed asphalt has been the name generally applied to bituminous limestone rocks which are reduced to a powder, then laid on the concrete foundation, and rammed with hot punners or tampers and further consolidated with a light roller, the surface being completed by using special, hot, curved tampers to give a fine finish. Trinidad asphalt is treated by being compressed first with light rollers, and subsequently with heavier ones. Specifications now generally state that the work is to be of standard (rock) asphalt or Trinidad asphalt, as a means of distinguishing these different materials, both of which are compressed pavements.

423. The method of carrying on the operations of laying rock asphalt is to heat the powder in revolving cylinders to a temperature of from 250° to 300° Fahr., according to the state of the weather, in order to evaporate the superfluous moisture, care being exercised to keep the particles as free as possible, so that they will remain separate without being calcined. This process of heating occupies from three to five hours, and if the overheating of the bitumen is allowed it becomes fused, while underheating prevents the asphalt from binding properly. Asphaltic rock containing from 9 to 10 per cent. of bitumen is that most suitable in all circumstances. The powder thus heated is conveyed to the carriageway where the asphalt pavement is to be formed, in iron-lined carts, covered with hemp cloths, in order that it may not lose more than 20° of heat during transit and may retain its property of adhering under compression.

As the surface of the concrete foundation must be perfectly dry when the asphaltic powder is spread upon it, the work can only be accomplished during suitable weather. Dry weather is absolutely essential, as the best asphalt laid upon damp concrete draws up the moisture, which is converted into steam by the heated powder; the steam escapes through the asphalt, and fissures appear when the surface begins to wear. When the ingredients are mixed in improper proportions, the pavement has a tendency to creep and its surface becomes wavy. Neglect of these matters led to failure in many of the earlier attempts to construct a satisfactory street covering with this material.

424. Spreading the Asphalt Powder.—The heated powder is spread to a depth of about 3 inches for a 2-inch and 2 inches for 1½-inch finished depth of pavement upon the concrete foundation, and raked so as to present a layer of regular depth and uniform surface. The powder is then rammed with iron disc-shaped punners, weighing about 10 lbs., heated to prevent the adhesion of the powder. The punning or tamping should be performed lightly at first to ensure an equal thickness of the material, and the force of the blows subsequently increased until the whole is partially solidified. The pavement is further consolidated with a hand roller weighing about half a ton, the process being repeated so as to compress the asphalt to the required thickness of 2 inches, and finished with suitable curved hot iron tools until it is quite cool.

A light sprinkling of cement is generally thrown over the finished surface, a few hours after which the pavement is ready for traffic.

Val de Travers asphalt has a tendency to crack under hot sunshine; and in order to obtain more reliable results it is blended with other rocks, such as Seyssel and Servas. The operation of mixing is accomplished previous to grinding.

In the case of asphalt pavements laid with bituminous limestone powder, as described above, the ultimate consolidation does not take place till some considerable time after the thoroughfare has been opened to traffic. It is not until then that the actual wear of the pavement commences.

425. Trinidad Asphalt.—This asphalt is generally laid on a Portland cement concrete foundation similar to that for other kinds of carriageway pavements, and upon this a bituminous concrete course may be advantageously introduced, the wearing surface being united to it in one mass, preventing, or at all events minimizing, the tendency to form a wavy surface and cracking.

In addition to concrete foundations, existing pitched and cobblestone pavements and also macadam roads may be used for carrying the asphaltic wearing surface. This is accomplished by first cleaning out all earth and soft material from the joints; the surface is then brushed and watered to receive a grouting of cement or hydraulic mortar, and so fill up the depressions, and on this the binder course is spread. This method has been extensively adopted in the City of Liverpool and elsewhere, while in the United States it is generally adopted.

The manufacture of bitumen requires very careful manipulation to ensure a satisfactory and durable carriageway pavement. It is found in a crude state in the Island of Trinidad, B.W.I., and in South America, the Pitch Lake in Trinidad being the best source and at the same time furnishing the most valuable kind. The hard or compact bitumens are the most useful varieties, but they require to be purified or refined in order to free them from foreign matter. Refined bitumen is hard and brittle, and consequently requires the addition of a residuum oil as a flux. The proportion of the flux varies from 10 to 12 lbs. of oil to 100 lbs. of refined bitumen, according to the quality of the flux, hardness of the bitumen, and the purpose to which and the locality where the asphalt is to be applied. The bitumen is melted and raised to a temperature of 300° Fahr. before the oil, previously heated, is added to the mixture, and it is then agitated by mechanical means or by a blast of air until it has acquired the desired properties.

When in this particular condition, it forms the matrix of the asphalt, the aggregate being composed of clean sharp sand and stone or limestone dust. The proportion of these ingredients for carriageway pavements varies, according to the character of the aggregate, amount and nature of the traffic, and the climate of the locality where it is to be used.

As the success of this particular kind of pavement depends upon the care and judgment exercised in selecting and combining the materials, and on the laying of the pavement, skilled labour and special machinery only are employed.

The ingredients, previously heated, after being measured according to the circumstances just mentioned, are thoroughly incorporated in a mixer, when the composition is ready for use. It is conveyed in specially constructed and equipped carts to the street where the asphalt is to be laid, and there spread with iron rakes to a depth which will give the desired ultimate thickness, varying from 1½ inches to 2 inches when compressed by means of a steam-roller weighing 7 tons, which is equal to a compressive force of 170 lbs. per inch of width.

To obviate creeping, and consequent cracking when laid on a Portland cement concrete foundation, it is advisable in streets where the traffic is considerable to spread a cushion layer of bituminous concrete, or "binder," as it is termed, between the foundation and the asphalt forming the wearing surface. This binder course is purposely made more plastic or cementitious than the upper or wearing layer of asphalt, so as to combine the whole in a homogeneous mass.

In this country the composition of the wearing surface of compressed Trinidad asphalt is approximately as follows:—

Asphaltic cement, from	12 to 15	per cent.
Sand, from	83 to 70	,,
Pulverized carbonate of lime, from	5 to 15	,,
	100 100	

In order to make the pavement homogeneous, the proportion of asphaltic cement may be varied according to the quality and character of the sand. The carbonate of lime may be reduced, or entirely omitted, when suitable sand can be obtained.

For first-class carriageways the pavement is generally laid to a total thickness of 2½ inches, composed of—

Binder,	1 inch.
Asphalt surface,	1½ ,,
Total,	2½ inches.

Binder Course.—The binder course consists of a fine bituminous concrete composed of clean broken stone, slag, or gravel, in pieces not exceeding 1½ inches in their largest dimensions, thoroughly screened, and asphaltic cement made from Trinidad bitumen. The stone, slag, or gravel must be heated by being passed through revolving heaters, and thoroughly mixed by machinery with the asphaltic cement, in the proportion of about 15 gallons of the latter to 1 cubic yard of stone, slag, or gravel. The material thus treated is then conveyed to the work, and spread on the foundation with hot iron rakes, and immediately rammed and compressed with steam rollers, while the mixture is in a hot and plastic condition, until it has a thickness of 1 inch. The top surface of the binder course should be made exactly parallel with the surface of the pavement when finished.

Wearing Surface.—Upon the binder course the wearing surface or asphalt pavement is laid, the composition of which varies in the proportions stated at p. 396, the density of the pavement being determined as that best adapted to the climate and traffic. Damp subsoils and localities having a high percentage of rainfall require a pavement to cope with these conditions, composed of a greater average quantity of bitumen, which, when in comparatively greater proportion to the aggregate, reduces the life of the pavement under heavy traffic.

The sand and asphaltic cement are heated separately to about 300° Fahr. The pulverised carbonate of lime, while cold, is mixed with the hot sand in the requisite quantities, and is then incorporated with the asphaltic cement at the required temperature and in the proper proportions, in a suitable apparatus which will effect a perfect mixture.

The pavement mixture, prepared in the manner described, is then laid upon the binder course in one coat; it should be brought to the ground in carts or wagons, at a temperature of about 250° Fahr., and carefully spread by means of hot iron rakes. This must be carried out in such a manner as to give a uniform and regular surface, and to such a depth that, after having received its ultimate compression, it will have a thickness of 1½ inches. The surface is first compressed by hand rollers, after which a small quantity of cement is swept over it, and is then thoroughly compressed by means of a steam roller, the operation being continued so long as the roller makes an impression on the surface.

Fig. 138 shows a cross-section of asphaltic pavements of bituminous limestone and Trinidad asphalt.

426. It is interesting to note that Trinidad asphalt has recently been laid on a portion of the Victoria Embankment, London, near Blackfriars Bridge. The object of most experiments on this thoroughfare is to produce a surface smoother than ordinary macadam and without the necessity of forming a concrete foundation which is essential to all first-class pavements.

The portion of road thus paved was first stripped to admit of the asphalt paving being laid to new levels, having a contour of less rise than existed formerly. A layer of asphaltic concrete composed of granite chippings, a small quantity of sand mixed with the proper proportion of Trinidad bitumen, as already described, was spread and raked into shape and then consolidated, with a 10-ton roller, to an ultimate thickness of 3 inches. On this base the wearing surface coating, representing compressed asphalt of a thickness of 1½ inches, was spread and rolled till thoroughly consolidated. This method of construction, common in America, is practically new in this country, and is, in a sense, experimental. Whether the original filling material of the Embankment, affected by the rise and fall of the river, is of a sufficiently stable nature to suit a rigid or jointless pavement, remains to be seen.

427. Contour and Gradients.—As asphalt pavements are extremely smooth, surface water is easily drained from the thoroughfare; consequently, an excessive rise, or even the amount generally given to a pitched or wood-pavement, is unnecessary, a rise of about $\frac{1}{80}$ to $\frac{1}{100}$ of the width of the carriageway being in most circumstances sufficient. It is not advisable to lay a limestone rock asphalt pavement in streets steeper than 1 in 50 or 1 in 60, and Trinidad asphalt 1 in 25. On steeper gradients they afford but little foothold for horses, and are consequently not safe to travel over.

Foundations.—A solid unyielding foundation is indispensable for all asphaltic pavements. It should be laid in a similar manner to that described for a pitched or wood pavement. Considering that the thickness of the asphalt is only about 2 inches, it is essential that the concrete be of first-rate quality; while in some cases the depth may be advantageously increased to 9 inches to the desired contour, and floated with cement mortar.

428. There are several other forms of asphaltic pavements, one of the latest being asphaltic composition blocks, a form of paving used in America which is said to give a better foothold for horses than the ordinary or "Standard" and Trinidad asphalt.

The composition consists approximately of 13 per cent. asphaltic cement, 10 per cent. limestone dust, and 77 per cent. crushed gneiss, traprocks or basalt, the latter giving the best results. The treatment is similar to ordinary methods for heating and mixing,

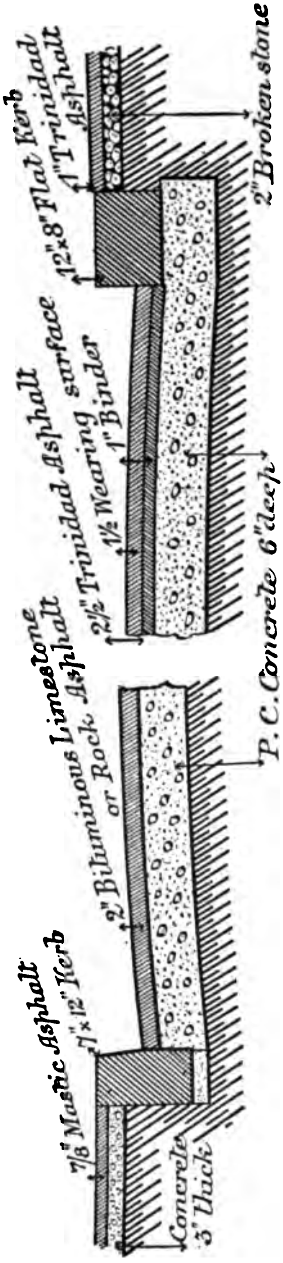

FIG. 138.—Cross-section of asphalt pavement.

and the composition is placed in moulds 12 × 4 × 3 inches, subjected to a pressure of 2 to 2½ tons per square inch, and slowly cooled in water. These blocks may be laid on a concrete foundation, or on a gravel bed with sand bedding, laid close-jointed, and in cold weather.

Lithofalt is an asphalt paving introduced by the Limmer Asphalt Company, to meet the requirements of those who are not desirous of investing in such an expensive pavement as mineral rock asphalt, and for places where the traffic is only moderately heavy. It is a medium between rock asphalt and tar macadam and tar paving. Lithofalt makes an excellent paving for side streets and small towns; it is perfectly sanitary, is impervious to moisture, and easily cleansed. Moreover, it is comparatively noiseless, and admits of greater ease of traction than the asphalt paving. This form of paving has been laid in several important London boroughs, in Belfast, Edinburgh, etc.

Carbolithic asphalt is another variation of asphalt paving. In the manufacture of this material only the densest and heaviest oils are utilized, and these in minimum proportions. Carbolithic asphalt is supplied ready for use in powder, and only requires heating before being applied.

Under normal conditions the asphalt after being melted is spread from 1 to 1½ inches thick upon the previously prepared foundation, consisting, for footpaths, of well-rammed hardcore or clinkers, and for roadways, of either hardcore or concrete, and then thoroughly punned with a hot iron. In special cases and for footways in better-class thoroughfares, the surface may be sprinkled with finely riddled Buxton limestone, Derbyshire spar or Penmaenmawr granite chippings. The surface of the asphalt, however, as supplied, is excellent for its purpose, and it is seldom considered necessary to apply any further top dressing.

The specific weight of carbolithic asphalt is about 150 lbs. per cubic foot, but this varies slightly in accordance with the climatic conditions of the locality in which it is to be used.

A few of the chief features of carbolithic asphalt are said to be its impermeability to moisture, durability, good foothold for horses, practically free from noise, economical in first cost and in maintenance, extreme toughness and closeness of grain.

429. Asphalt pavements for carriageways are eminently suited for cities and towns having comparatively level thoroughfares. Among other advantages which these pavements possess, the following may be mentioned. They are jointless, have a smooth even surface, are absolutely impervious to moisture, and dry quickly after a fall of rain; they are comparatively noiseless, and easy of traction, consequently they are pleasant to drive over, owing to the absence of vibration and concussion. They are very durable, quickly laid and easily repaired, a matter of considerable importance in thoroughfares where continuous wheel traffic exists, which greatly lessens

the inconvenience of long delays during renewals, and corresponding inconvenience to business people and shopkeepers. They neither absorb nor radiate heat, and having a smooth surface, they can be quickly and easily cleansed, and are, therefore, perfect sanitary pavements; they can be kept scrupulously clean by washing, which no other kind of street pavement is capable of in so effective a manner.

430. As these pavements are constructed, and maintained in most instances by contractors, it is the practice of the Asphalt Paving Companies to charge a certain price per square yard for laying according to the thickness required, and also to maintain the surface in good repair at a fixed price per square yard annually, for a definite number of years.

TABLE LVI.

The following table, showing the cost and life of asphalt pavements in London, has been compiled from data given in a report on carriageway paving prepared by Mr Oxtoby, Borough Engineer of Camberwell, in 1904.

DISTRICT.	Cost per yard super. with foundations.		Depth of Asphalt.	Life of Asphalt.	Cost of Maintenance.
	Compressed.	Mastic.			
	s. *d.*	*s.* *d.*	Inches.	Years.	
Bermondsey, .	12 0	11 0	1½	Depends on traffic.	...
Camberwell, .	...	10 6	1¾	...	...
Hammersmith, .	12 0	...	1½	...	...
Holborn, . .	13 0	7 6 (footways)	2 (carriageway) ¾ (footway)	15, heavy traffic. 25, light traffic.	3d.-2s.
Marylebone, .	13 0	...	2	15	8d.
Paddington, .	12 6	12 6	2	15-20	3d.-6d.
Shoreditch, . .	11 0	6 6	1½-2	10	...

This arrangement, therefore, does not admit of a direct comparison with other descriptions of pavement similarly situated, where constructed and maintained by the authorities' own staff; the cost of the annual maintenance, no doubt, is given, but as this will in most instances be a fairly remunerative figure, the actual cost for repairs, on different pavements, can only be arrived at approximately.

431. The life of asphalt pavements varies according to the nature of the covering, geographical locality, and the amount and description of vehicular traffic. It has been variously stated at from seventeen to twenty years, and in the borough of Holborn, where the rock asphaltic pavements are almost exclusively used, the life has been stated to be, in some instances, twenty-three years.

The period for this class of pavement for which the London County Council will grant loans is ten years, and in the absence of information from sources of recognized authority, the actual and annual cost of these pavements must, for comparison, be calculated according to the data available.

Taking, therefore, a similar area, as in the case of wood pavements and a life of ten years, the following figures are arrived at:—

TABLE LVII.

One mile of carriageway 30 feet wide—		
Standard asphalt, 2 inches thick, including 6 inches P.c. foundations, at 13s. per square yard,		£11,440
Contingencies,		750
		£12,190
Second ten years—refloating surface and laying pavement, 2 inches thick, at 10s. per square yard,	£9,240	
Contingencies,	400	
		9,640
		£21,830
Repayment of principal and interest—		
Foundations, life twenty-four years, proportion,	£859·37	
Pavement first ten years,	1988·25	
Pavement second ten years,	1988·25	4,835·87
		£26,665·87

This sum represents an average annual cost of 1s. 6·18d. per square yard during a period of twenty years; and to this figure must be added the cost of maintenance, which may be taken at, on an average, allowing two years' free upkeep, 8d. per square yard, or an inclusive cost of 2s. 4·18d.

The maintenance contract price varies, according to class of pavement and conditions of traffic, from 3d. to 2s. per square yard per annum.

CHAPTER XIII.

BRICK PAVEMENTS FOR CARRIAGEWAYS.

432. **Brick Pavements** for carriageways are extensively used in the United States, where they were first adopted in 1872. Many of the streets in the principal towns in Holland are paved with this material, particularly in Amsterdam and Rotterdam, where bricks are stated to have been employed for paving purposes for over 150 years. Bricks have not hitherto been used for paving to any great extent in this country, although there are towns with a medium traffic where it has been laid as a pavement; they are, however, much used in forming street crossings.

In Liverpool, "Tees scoriæ" bricks from Middlesbrough were laid as a trial in 1881; they were not, however, very successful, wearing unevenly and being extremely slippery. The unequal wearing was probably owing to the manner in which they were manufactured, as, on examination, many of the bricks were found to have large holes in them, where the materials had not fused together.

The chief experience with bricks for paving in this country has been obtained in the county of Staffordshire, while the town of Cheltenham has also made experiments.

433. The suitability of bricks for carriageway pavements depends on the quality of the clay from which these are made, the method adopted in manufacturing and burning them, uniformity of shape and size, and the extent to which they will conform to the tests for absorption, crushing strength, and abrasion. In addition to the bricks having to conform to certain standards in the directions mentioned, the specific gravity test, varying from 2·00 to 2·30, is at times adopted.

The characteristics which brick suitable for paving purposes should possess may be stated as follows:—

(1) It should not absorb more than 3½ per cent. of moisture in twenty-four hours, nor be acted upon by acids.

(2) It should be rough to the touch, afford a good foothold, and not be liable to become polished.

(3) It should be hard, but not brittle, give a clear ringing sound when struck, and not be liable to scale or to chip on the edges.

(4) When broken it should show a compact, uniform, and close-grained structure free from air-holes and small stones.

The composition of clay varies considerably, but most bricks are made from a hydrated silicate of alumina in combination more or less with other substances, such as magnesia, iron, lime, and potash. Alumina gives elasticity, and renders the material tough and binding; magnesia in small quantities renders the clay fusible; iron is advantageous, tends to make the brick more homogeneous, and aids in producing vitrification.

Lime in excess is injurious, and although infusible, is changed into caustic lime at high temperatures, and when exposed to the action of the weather, absorbs moisture, and causes disintegration. The alkalies, varying from 1 to 3 per cent., act as a flux in chemical combination with the silica and alumina.

Clay, to make satisfactory paving bricks, must be rich in silica, free from lime, and able to withstand, without fusing, a red heat for a sufficient length of time to render the bricks hard, homogeneous, and impervious to water.

The methods practised in preparing the clay previous to being manufactured into paving bricks vary considerably, but the essential points may be stated as follows, namely—(1) preparing and grinding the clay, (2) tempering, (3) moulding, (4) drying, and (5) burning.

434. In a paper on the subject of bricks for carriageway paving, M. A. E. Blizzard says that the process which has been found to produce the best results is as follows: "After adding to the marl a suitable portion of the rock, the whole is crushed through rollers, passed through a disintegrator, and made into stiff plastic by means of a pan. It is then passed through heavy clot rollers, which push it out in a solid continuous stream, and this is cut into the required lengths by a rotary parallel cutter. The advantage of the clot roller is that the air is gradually squeezed out as the clot is formed, reducing the chance of laminations. The clots are then pressed in a powerful belt-driven press worked on the toggle-lever principle. This gives a steady squeeze, top and bottom, of forty to fifty tons, thus allowing time for the remainder of the air to get out and for the particles to thoroughly unite. The apparent loss of time in squeezing is made up by the rapid up-and-down motion of the plungers. The clots are placed on a table having a revolving set of grippers, which pass them into the die and deliver the finished bricks on to an endless belt which takes them away.

"After pressing, the bricks are conveyed by the endless belt to a drying shed conveniently near to the ovens, in which they are afterwards placed (or they may be placed at once in the oven) in such a way that the hot gases generated in the mouths have free access to them. The ovens are of the intermittent down-draught type. The hot gases from the mouths pass up to the top of the oven and are then deflected down through openings in the floor to the flues below, which lead to the chimney. Many attempts have been made to build continuous kilns suitable for firing blue bricks, but so far without good results."

For all practical purposes, although all the tests previously mentioned are sometimes carried out, the suitability of bricks for paving purposes may be judged by their capacity for absorption and abrasion.

435. **Absorption.**—This test, which represents the probable effect of atmospheric action, is of great importance; it is one of the factors which determine the life of a brick pavement. The alternation of wet and dry weather, as well as frost and thaw, to which all pavements are subject at times, tends to disintegrate bricks, so that the less absorbent they are, the more durable and sanitary they will be. American specifications generally stipulate that paving bricks must not absorb more than 1½ to 3½ per cent. of moisture in twenty-four hours, although the time required for this test is occasionally extended to forty-eight and seventy-two hours.

436. **Abrasion.**—This test for paving bricks is also of importance, and is carried out in a somewhat similar manner to that used in testing road metalling. The pounding produced by horses' feet on most pavements, and especially on this class, causes the greatest amount of wear, so that the material which can withstand such treatment will, in all probability, be the most suitable and give the longest service as a pavement.

There are no standard conditions by which different bricks can be compared, the "rattle" or "tumbler" test being carried out with the bricks placed in it alone or with iron castings or other material introduced. The construction of the testing machine, the number of revolutions per minute, the duration of the test, and the percentage of loss, are all matters which have a direct bearing on the subject.

437. **Resistance to Crushing Power.**—So far as the resistance of bricks to crushing is concerned, it seems remarkable that some specimens should possess a greater crushing resistance than most kinds of granite, although they are not so tough. Staffordshire blue bricks, tested by Kirkaldy, gave the crushing resistance at from 15,000 to 18,000 lbs. per square inch, while the strength of granite, similarly tested, varied from 12,000 to 18,000 lbs. per square inch.

In the United States, where particular attention is paid to the manufacture and burning of bricks for paving purposes, recent tests at Watertown Arsenal showed that 22,000 lbs. per square inch was attained. In some cases the crushing resistance has reached the abnormal figure of 30,000 lbs. per square inch, but 7,150 lbs. per square inch appears to be the average in America. The tests are carried out there on a very extensive scale, testing laboratories having been established, equipped with suitable apparatus for this purpose.

438. **Size of Bricks.**—The standard size of building brick in this country is 9 inches x 4½ inches x 3 inches, and it was considered that this would also form a convenient size for paving purposes.

In the United States the sizes vary considerably, but the dimensions of brick mostly used are 9 inches × 4 inches × 3 inches. They are formed with square edges and rounded nosings, while many are made with rounded tops. The square edge makes the best joint, is less noisy, and more readily cleansed, although the arrises become chipped by the action of the horses' feet.

439. Foundations.—Many of the brick pavements in the United States are simply laid on the natural ground, previously rolled; in other instances, slag, gravel, or ordinary macadam has been used and steam-rolled before the brick pavement is laid.

Now, however, the best work is being carried out by forming a concrete foundation similar to that used for first-class pavements in this country, and no doubt the success of the paving will be greatly enhanced, and the life or service of the bricks extended, if laid on concrete.

Laying.—The bricks are laid on a cushion of sand, as in the case of a pitched pavement, at one time spread to a depth of 3½ inches, but now generally from 1 inch to 2 inches in thickness. The bricks are laid on edge close up to the kerbs without any channel courses, at right angles to the centre line of the thoroughfare, or at an angle of 60°, which is preferred in some towns. The bricks are, for the most part, laid with as close a joint as possible, but in some cases with a ⅛-inch space to allow for grouting. The irregular shape of the bricks generally permits of a sufficiently wide joint for this purpose. Closers are specially made to avoid cutting the ordinary bricks, and vary from ¼ to ¾ lengths. The paving is then rammed or rolled with horse-rollers drawn by men, or by light steam-rollers, any defective bricks being replaced before filling the joints.

Grouting.—This is effected with clean river sand, cement, or pitch. In the case of the two latter materials, the joints are filled by means of an iron funnel-shaped tool, having a small hole at the bottom, the flow of the grout being regulated by a plug valve. ?

The surface is finished by covering the pavement with coarse sand from ½ inch to 1 inch in thickness, which is allowed to remain for ten or twelve days and then swept off, the traffic passing over the pavement meanwhile.

Specifications for brick pavements differ widely in their requirements, and, as already mentioned, no standard for testing the quality, or the method of construction, has been arrived at.*

440. Advantages and Defects of Brick Pavements.—The advantages of a brick pavement are stated to be ease of traction and fairly good foothold for horses; it is easily repaired and cleansed, consequently it is sanitary; and it is durable under moderate traffic. The defects of brick pavement arise principally from the lack of uniformity in shape and quality, which necessitates the making of a wide joint in most cases, while the soft or more porous bricks are liable to disintegrate under the action of traffic or the effects of frost.

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* The details of the specification adopted by the Board of Public Works, Indianopolis, U.S.A., for the laying of brick pavement are given in the first edition of this work, p. 363.

441. Life of Brick Pavements.—In regard to laying, Mr. Blizzard says that the "subsoil being made solid, a bed of screened ashes is all that is necessary. The bricks lie and wear most evenly when laid herring-bone, with one or two courses parallel to the path on both sides, and angle pieces specially made to join up to these. Grouted up with fine ashes, and a sprinkling of ashes being thrown over the finished pavement, it is ready for traffic, which will soon wear the ashes into the joints and make a perfect grout. Sand and cement are sometimes used for setting, but it is an unnecessary expense.

"Good blue bricks may be relied upon to last for forty years without repair under the heaviest wear, and may last very much longer.

"For residential areas, or streets where the traffic is not heavy and quick, bricks possess some advantages over other kinds of paving. They give a perfectly true surface, are most sanitary, being non-absorbent, are easily washed down, are not more slippery wet than dry, give a good foothold for horses (having rounded arrises), are not as noisy as stone or granite setts, and will stand a great deal of wear—but that is a point upon which I am sensible that surveyors will require to be satisfied.

"A brick-paved street may be repaired more cheaply than any other; and with a cement filler no special apparatus is required, as for pavements where asphalt or pitch is used; and the offensive smell of the latter is avoided.

"In 1900 we sent to Cheltenham a quantity of bricks, which were laid in New Street, where the traffic from a railway goods yard passes over them; and after two years' wear the late Borough Surveyor, Mr. Joseph Hall, in publishing an article on brick paving, remarked that the traffic has included some of the heaviest in Cheltenham; but this is only coal wagons, and carts, and railway delivery trolleys. The section which takes the heaviest traffic has been laid down about two years, and shows no sign of wear, although bricks have been chipped. Drivers tell me that the foothold is all they can desire. I have driven over it myself frequently, and have found no difficulty, although I anticipated some trouble from frost. The conclusion I have arrived at is, that if the same care be exercised in forming the foundation, in selecting the materials, and in laying them, as is done with wood paving, a more efficient and sanitary pavement will be obtained at a less cost."

Five years after this piece was laid, that is, in 1905, the present Borough Surveyor reports as follows: "With regard to the experimental piece of blue brick paving laid down in one of the streets here, the paving comprises an area of 300 square yards, and was laid down in August 1900. The foundation consists of a thickness of 6 inches of cement concrete, and the bricks are laid on a bed of sand and grouted in with pitch. The paving is close to the Great Western Railway Company's coalyard, and receives a fair amount of heavy traffic. At present there are holes, due to the traffic in the centre of the road, about ¾ of an inch deep. Speaking generally, the paving has worn fairly well; but I do not think the life will be more than, say, ten years, and before this time the middle portion will have to be relaid. I am of opinion that bricks of this character are not suitable for the paving of public streets, except where the traffic is very light indeed."

In America, where the experience of this description of pavement, laid on concrete foundations, has extended to a period of about twenty-five years, the life time is stated to be from fifteen to twenty years under ordinary conditions. In many instances, where the paving has been down for ten or twelve years, it is reported to be in good condition and but little worn.

The durability, of course, depends greatly on the nature and amount of wheel and hoof traffic, and also the climatic conditions, which latter, it must be remembered, are more severe than in this country.

442. Cost.—The average cost of constructing a brick pavement in the United States is 5s. 8d. per square yard.

It is reasonable to suppose that brick paving could be carried out in this country, when the bricks can be obtained within a moderate distance of the locality where they are to be laid, for 6s. 4d. per square yard, or 8s. 10d. per square yard including a concrete foundation 6 inches deep.

TABLE LVIII.

The cost of the blue bricks, already referred to by Mr. Blizzard, is as follows :—

	Per yard super.				
	s.	*d.*		*s.*	*d.*
Blue bricks, 9 inches × 4½ inches × 2¼ inches, laid on ashes and grouted with ashes, ...	2	3	to	2	6
Blue bricks, 9 inches × 4½ inches × 2 inches, laid on ashes and grouted with ashes, ...	2	2	to	2	4

Taking London only, the approximate figures of the cost of brick compared with other kinds of paving are, exclusive of foundations, and not taking into account the life of the respective materials, stated as under :—

TABLE LIX.

	Per yard super.	
	s.	*d.*
Bricks, ...	7	6
Creosoted yellow deal, ...	8	0
Jarrah or Karri, ...	11	0
Compressed asphalt, 2 inches thick, ...	10	0
Granite setts, ...	13	0

The average cost of street paving per square yard in Philadelphia in 1898, when it touched the lowest figure, was granite blocks, 9s. 9d.; street asphalt, 6s. 0½d.; and bricks, 5s. 8½d.

CHAPTER XIV.

TAR MACADAM.

443. This description of pavement is very suitable for thoroughfares in suburban districts and towns with medium traffic. It is by no means a new form of paving material, having been laid in Nottingham over sixty years ago, as well as in other centres. Although tar macadam has not been much used hitherto, it is now being extensively employed by reason of the methods of manipulating the ingredients being greatly improved. The primitive methods formerly employed in mixing and applying the material probably account for many of the failures experienced in using tar macadam.

To obtain good results it is considered necessary that the stones should be thoroughly dried by heating. This process was formerly carried out by forming a stack composed of wood, coke, and the stones to be dried, and setting fire to the heap. It occupied from four to ten days, depending on the size of the stack of material, and had the effect, in many instances, of calcining the stones, which rendered them practically useless as a paving material. The tar was invariably used in a crude state, or allowed to stand in a large tank for a considerable time to allow the water and volatile oils to escape or come to the surface. The practice at the present, and indeed for some considerable time past, is to eliminate the water and volatile matter by boiling or refining the tar, which has an important bearing upon the ultimate results.

This class of pavement is very much superior to ordinary macadam in wearing qualities, consequently more economical in upkeep, and, being waterproof, mud and dust are practically non-existent. The initial cost, however, is considerably greater than in the case of ordinary macadam, and its use on an extensive scale, on county roads at least, is considered prohibitive.

444. The description of materials generally employed in this class of pavement are limestone, Kentish rag-stone, furnace slag, and many of the road stones produced from rock of igneous origin which possess characteristic features. The former are those mostly employed, as it is considered that, being somewhat porous, the limestone and slag absorb the tar. This feature exists to a certain extent in limestones, but it is apparent that stones capable of being impregnated with tar owing to their soft or porous nature are of little use as a paving material. A hard stone which produces a rough fracture when broken is superior to most other kinds of material for tar macadam, while stones which are largely composed of free quartz in large crystals are not so satisfactory.

445. Various methods are adopted for drying the material before treatment, and machinery has recently been introduced for mixing the stones with the tar and extensively used at the various centres where this paving material is produced. The preferable arrangement for drying the stones consists of a kiln or drying floor formed of cast-iron plates, generally 4 feet × 3 feet × 1 inch thick, fixed about 2 feet above ground level and supported on 4½-inch brick dwarf walls. Provision is made by means of openings in the walls to allow the heat from the fires to circulate freely under the floor on its passage to the chimney. These drying floors are made of a size of about 24 feet × 20 feet, and are capable of accommodating a considerable quantity of material during the drying and mixing process, the whole operation being carried out under cover. Large coppers, capable of holding about 80 gallons each, for boiling the tar are placed at one end of the building, the heat from the fire flues accomplishing this object. The tar is generally boiled for two or three hours, depending on its quality, pitch being added to stiffen the tar, and creosote oil used if found necessary. Distilled tar heated, but not brought to the boiling point, is the most preferable kind of tar to use. The mixing of the material is performed by spreading a layer of stones from 6 inches to 1 foot in depth, according to the amount of drying necessary, the layer being turned over two or three times, according to circumstances. The stones in a warm state, but not too hot, are then treated by hot tar being poured over them by means of buckets, and so applied that all the stones receive an approximately equal amount of tar. The materials are turned over and mixed, the process being continued for some time in order to, as far as possible, incorporate the ingredients thoroughly. The amount of tar which is necessary to be applied to each ton of road stones, for this class of pavement, generally averages from 8 to 12 gallons, depending on the kind of material employed and the gauge to which the stones are broken. The treated material is usually stored for a few weeks in order that the superfluous tar may drain off, which period of time may indicate the affinity of the stones to absorb the tar, or the amount of tar necessary in the mixing operations to properly coat the stones.

The excessive use of tar and overheating the material are unnecessary, as the induced heat in the stones throws off the surplus tar and leaves the surfaces but slightly coated, especially in the upper portions of the stacked material.

Spreading the material prepared as described, or, if for immediate use, adding a proportion of pitch to the tar during the refining process, is performed in the usual way, but care must be exercised to spread the material uniformly, as, being treated with tar, it is somewhat difficult to manipulate compared with untreated road stones.

446. The road to be repaired is, in most instances, stripped, and the old material removed to a sufficient depth to admit of the treated stones or tar macadam being spread to the desired thickness. The foundation should be properly levelled and contoured and moderately rolled to ensure equal consolidation, previous to the tarred material being spread. Any inequalities or weak places should be made good by applying material of a hard nature, previously excavating the soft or earthy matter.

The material when ready for use is spread on the prepared surface, generally in two coats, but sometimes in three layers. The first, composed of 2¼-inch material, is spread to such a thickness that when rolled it will measure 4 inches in depth, and then a layer of ¾- or 1-inch material is spread so as to fill the interstices, the whole being well rolled or consolidated, and finished by sprinkling a light coat of slag dust or other suitable material over the surface. In some instances the road coating, from 4 to 6 inches in depth, is rolled in the usual way and then grouted with a boiling mixture of tar, pitch, and creosote oil, which fills the vacant spaces between the stones. Small stone chippings are added, and, by further rolling, the surface is made perfectly smooth and compact. By this method of making a tarred macadam road the quantity of tar used is generally excessive, which gives trouble during hot weather. The application of boiling tar to the cold road stones chills the mixture to a certain extent, which has a detrimental effect and detracts from the wearing qualities of the material.

Repairs on this class of pavement on roads of medium traffic are not necessary for some considerable time after being made—indeed, owing to the elastic nature of the matrix or binding agent, some time elapses before the coating is completely consolidated. Small depressions or hollows in the surface may be repaired by picking up these places, sweeping thoroughly, applying hot tar with a brush, and then filling the hollows with tarred chippings and consolidating the patches by rolling. Extensive repairs are generally carried out by picking up the old surface, removing all useless material and detritus, applying a thin coat of hot tar, and spreading a 2¼-inch layer of treated stones and a proportion of tarred chippings, the whole being consolidated by rolling. Tar macadam pavements may be preserved and kept in good condition by painting or floating the surface, after being thoroughly cleansed, with hot tar and sprinkling stone chippings or slag dust over the area so treated. This operation may be necessary every two or three years under ordinary traffic conditions.

447. The advantages of tar macadam over ordinary macadam are, increased durability, practical imperviousness to moisture, and capability of being swept perfectly clean and even washed without injury to the surface. The road stones being held firmly in position by the binding action of the tar, internal movement or abrasion does not take place; consequently the resulting mud and dust common on ordinary macadam roads, under certain weather conditions, are practically non-existent on tar macadam, except such as is produced by the natural wear of the material at the surface. It is practically noiseless, and presents an asphalt-like surface, which offers but little tractive resistance to traffic. The surface is not disintegrated during extreme weather conditions, such as alternating frost and thaw.

The disadvantages are those common to asphalt pavements, being slippery during frosty weather, which is also a difficulty on ordinary macadam roads. The cost of tarred slag macadam or tarred limestone as a surface road covering is too great to admit of general use. The preparation of the old road surfaces for reception of the prepared material with the contingent expenses for carting and labour increases the cost per square yard, and the inclusive cost appears to prohibit its adoption on an extensive scale on rural main roads.

Tar macadam has been extensively employed in Nottingham, Battersea, on the Thames Embankment, Ayr, Glasgow, Leith, and many other centres.

Slag, even of the best quality, cannot be considered a sufficiently strong material to withstand heavy traffic, such as traction engines and motor wagons. Similarly limestone, which is more or less an absorbent material, is much too soft to expect good wearing results under even ordinary traffic.

The durability or life of tar macadam pavements depends, of course, on the amount and nature of the traffic, but is generally estimated at periods varying from three to ten years, although cases are recorded where this class of pavement has been in use for longer periods.

448. The cost of laying tar macadam varies greatly in different localities, depending on the description of stone used, the method adopted in manipulating and mixing the material, the distance from the source of supply, depth to which it is spread, whether the old surface requires to be picked up and the material removed, or the tarred stones are spread on the existing road surface. In Nottingham the cost per square yard averages from 1s. 9d. to 2s., and at Battersea 3s. 6d. to 4s. 6d. per square yard. The annual cost of repairs during the life of a tar macadam pavement varies considerably according to the amount of traffic and other conditions. Small repairs may be carried out for about ½d. per square yard, while refacing will cost about 1s. per square yard.

Other methods of practically accomplishing the same results as are claimed for tar macadam are described in Chapters VIII. and IX.

CHAPTER XV.

CONCLUSIONS.

449. It will be apparent from the description of the different materials which are at present employed in the construction of a first-class carriageway pavement, that it is not an easy matter to decide on the particular description of material for this purpose, suitable for the varying circumstances met with.

Apart from the durability of the paving material to be employed, though this is of the greatest importance, many considerations have to be examined closely, as, at the present time, they enter largely into the selection of a pavement suitable to the varying conditions and circumstances which exist in different towns. The most important points to be considered are, the nature of the gradients and foothold, description of traffic, width of the thoroughfares, the class of property facing the street, facility of cleansing, noiselessness, smoothness, economy of construction and subsequent maintenance, as well as the climatic conditions.

In cities and towns where the residential and manufacturing portions are somewhat separated from one another, and where the nature of the traffic and gradients vary considerably, an opportunity is offered for using all recognised kinds of paving material suitable to the particular situation and circumstances.

There is not at present, it may readily be inferred, any one class of pavement which possesses all the properties necessary for fulfilling the requirements mentioned above. On sanitary grounds alone impervious pavements are a necessity which, by reason of the methods adopted in constructing them, limit the use of certain kinds of material where heavy and continuous vehicular traffic has to be accommodated.

450. There is a consensus of opinion that granite setts properly laid form the cheapest and most durable pavement. It does not, however, present a smooth and regular surface after a few years' wear, especially when laid with wide joints, and this is considerably augmented by the frequent disturbance of the pavement in connection with repairs to gas, water, and other mains. The principal disadvantages of this class of pavement, however, are that it is noisy, and is liable to become slippery through wear, on which account it has been practically abolished as a paving material in the fashionable quarters and business thoroughfares of cities and large towns. No doubt the wide joint has something to do with the great noise inseparable from a pitched pavement, as, after a time, considerable vibration is set up, the wheels of vehicles bumping from stone to stone, causing wear and tear in an excessive degree both to the traffic and to the pavement itself. This vibration may also cause damage to the surrounding buildings. In several instances, however, where heavy loads form the great bulk of the traffic, such as in Manchester and other cities, granite setts are regarded by the authorities as the only possible form of paving both in the matter of wear and in affording the best foothold for horses.

451. Soft wood pavements or yellow deal blocks are still extensively used in London as well as in many provincial towns of medium traffic. The great advantage of soft woods, as has already been pointed out, is that the initial cost is less, while, at the same time, in London at least, the contractors are allowed a maintenance allowance ranging from 6d. to 1s. 3d. per yard super. per year over the whole area laid. The Australian hard woods have also made very considerable progress as paving materials. The first cost of hard wood pavements is undoubtedly greater than that of soft woods, but the durability and hygienic qualities of this class of paving material are such that it is replacing granite setts and the soft woods.

Hard wood paving laid with a close joint, the blocks of which have been previously dipped in a bituminous composition, wears very regularly and is comparatively noiseless, and its relative position on this point in connection with other pavements has already been given in the chapter dealing specially with hard woods.

452. Asphalt forms an ideal pavement. It is absolutely impervious; it affords no lodgment for filth, and, as it retains its camber, the surface drainage is rapid and effective. It is more easily cleansed than any other pavement, so that, from a hygienic point of view, it stands far in front of all other pavements. It retains a smooth surface, and is preferred by residents in streets where it is laid, because the wheels of vehicles passing over it make but little noise.

Unfortunately this otherwise excellent pavement, particularly that formed with rock asphalt, on account of its extreme slipperiness during certain climatic conditions, is disliked by horse owners, who, of course, use the streets most. For this reason rock asphalt cannot be laid on steeper gradients than 1 in 60. On comparatively level thoroughfares this defect can be greatly diminished by thoroughly washing the surface. Unfortunately, however, experience has shown that it is practically impossible in busy streets to keep the surface so clean as to prevent it becoming greasy in damp weather, and statistics have shown that more accidents occur on asphalt than any other form of paving, from this cause.

Sanding the surface, however, is resorted to at times to increase the foothold; but this has a tendency to wear the pavement, and ultimately results in mud being formed. This is also a temporary measure, however, and repeated applications of sand are necessary at times to render the pavement safe for travel.

The pavements which give the longest service should invariably be chosen, as, when other things are equal, it is to be preferred, because the renewal of the pavement in any of the principal thoroughfares of a town necessitates the closing of the street, which causes great inconvenience and seriously interferes with business. Although the first cost may be greater, that which is most suitable for the traffic and the locality is the cheapest in the end, and has the additional advantage that the streets are less frequently closed for renewals.

The concentration of traffic upon subsidiary streets, on account of the renewals to the main thoroughfares, occasions a state of disrepair on these roadways beyond what would result from the ordinary or legitimate traffic.

453. On the question of safety or comparative slipperiness on granite, wood, and asphalt pavements, the following table, prepared by Mr. Haywood, from exhaustive observations made in 1873, on the accidents to horses on carriageways in the City of London, is given*:—

TABLE LX.

City of London: Comparative Slipperiness of Carriageway Pavements.

Pavement.	Distance travelled before a horse fell—in miles.			
	Dry.	Damp.	Wet.	Average of 50 days.
Granite, ...	78	168	537	132
Asphalt, compressed, . .	223	125	192	191
Wood (Improved Wood and Ligno Mineral),	646	193	432	330

His remarks in connection with these observations give interesting details, and are as follows :—

"Slight rain makes both asphalte (rock) and wood more slippery than they are at other times. On asphalte the slipperiness begins almost immediately the rain commences; wood requires more rain before its worst condition ensues. The slipperiness lasts longer upon wood, on account of its absorbent nature, than it does upon asphalte; when dry weather comes after the rain, then asphalte is in its most slippery state, and the horses fall on it very suddenly; on wood their efforts to save themselves are more effectual; wood also is frequently in that peculiar condition of surface in which horses slip or glide along it without falling. A small quantity of dirt upon asphalte makes it very slippery; wood requires a large quantity. Slipperiness can be temporarily cured on both pavements — on the asphalte by sprinkling it with sand, on the wood by sprinkling it with gravel. The result in both cases is dirt. The sand thrown on asphalte helps to wear it out, the gravel thrown on wood tends to preserve it. When a horse falls on asphalte it has great difficulty in getting up; on wood it rises more readily."

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* *Report on Accidents to Horses on Carriageway Pavements*, by G. William Haywood (1874).

In thoroughfares crowded with traffic, the continual stopping and re-starting of heavily laden vehicles is very trying to horses, especially when the pavements are in a greasy condition, after a slight shower of rain or during the prevalence of fog. Washing the surface and applying fine gravel to a pitched pavement increases the foothold considerably, while the same treatment of soft wood pavements has the additional advantage of assisting in preserving the timber by reason of the small stones being crushed into the surface and so indurating it.

454. There is a marked difference between the description of pavements employed in large towns where the financial position ensures that the best form suitable to the locality and interests of the inhabitants can be provided, compared with those in provincial towns and urban districts, where, as a rule, the financial resources are limited. In the latter, these, to a great extent, restrict the use of first-class pavements, and in the majority of cases a less expensive class of road covering is sufficient for the purpose. Pitched pavements, with or without a rigid foundation of concrete, are generally adopted, especially in manufacturing towns where a smooth and noiseless paving is not of much consequence; and when the material is of a durable nature this description of roadway is ultimately the most economical, although the first cost may be considerable. It should, however, be understood that the cheapest pavement in first cost is not always the most economical, because it has been proved that the most suitable for the traffic is the most satisfactory and economical in the end. A heavy annual expediture for maintenance generally indicates that a restriction of initial expenditure in constructing a carriageway pavement has been the main object, rather than suitability and efficiency, during its lifetime.

In districts where the traffic is medium to light, and the thoroughfares comparatively level, tar macadam may be advantageously adopted. It forms a smooth impervious pavement when properly executed, and has the additional advantage that when suitable material can be conveniently obtained it can be constructed at a comparatively low figure.

Ordinary macadam, although the most expensive roadway to maintain where there is a heavy wheel traffic, has the advantage of possessing the best foothold for horses. On light trafficked town thoroughfares a steam-rolled macadam road is the cheapest form of construction, and when properly made with approved materials little mud or dust results compared with traffic consolidated roads, and is the class of roadway generally preferred by residents in suburban districts. Since, however, the arrival of the motor car, involving a greatly increased speed of travelling, another factor has entered into the matter of road construction which must largely modify, if not revolutionize, former requirements.

455. The great difficulty in comparing one class of pavement with another in regard to the durability of the material precludes any definite comparison being made as to the respective lives of road-paving under varying conditions or of their comparative economical advantages. As this can only be obviated by direct observation, it is desirable that such records should be made periodically under proper regulations and in a uniform manner. It is essential that a careful census of the hoof traffic and the wheel traffic be made, so that the actual amount of traffic tonnage, both fast and slow, reduced to a standard, passing over any street, can be accurately ascertained for a given period; this is generally stated in tons weight of traffic per yard of width of roadway per annum. From these data of the actual cost of construction and the amount expended for annual maintenance, reliable figures for comparison would be obtained. This census, while applicable more particularly to large cities and towns, would likewise be of great advantage if applied to provincial towns and country districts where there is a considerable amount of traffic passing over the roads. No doubt the amount of tonnage would fluctuate considerably at different seasons of the year, especially in country districts, but a fairly accurate record of the traffic could ultimately be arrived at.

Many records have been kept in the principal cities of the number of vehicles passing along a particular thoroughfare, but the approximate weight of each individual vehicle and its load, and the width of the roadway not being given, the information is obscure and void of any real value, except perhaps as a general statement of facts.

No doubt some difficulty would arise in regard to hoof traffic which, in many instances, causes more wear to the pavement than the wheels of vehicles; still more definite data might be collated, and a standard adopted by which the traffic passing over a road could be calculated.

456. Isolated instances of the amount of traffic and the number of vehicles passing over some thoroughfares in London are recorded, which are here given:—

Table LXI.

Locality.	Vehicles.	Tonnage.
Westminster Bridge Road, 1899.	3754 (west side) in 12 hours.	334 tons per ft. in width of road in 12 hours (6 a.m. to 6 p.m.).
" "	3014 (east side) "	283 tons do. do.
Strand, 1890.	1228 per hour and 15,000 from 8 a.m. to 12 midnight. Omnibuses are included in this number, and vary from 360 to 444 per hour or about 37 per cent. of the total number of vehicles.	
Euston Road, Western end, 1895.	Omnibus traffic equals 7·72 per cent. of the total weight of traffic.	575,544 tons per yard in width per annum.
Euston Road, Eastern end, 1894.	Omnibus traffic equals 31·8 per cent. do., and 19 per cent. of the total number of vehicles. The average number of omnibuses traversing Euston Road is 250 per hour.	411,318 tons per yard in width per annum.
Piccadilly, 1899.	1497 per hour, of which 423 are omnibuses, being equal to about 28 per cent. of the total number of vehicles.	
Cheapside, 1899.	661 per hour, of which 384 are omnibuses, being equal to about 58 per cent. of the total number of vehicles.	
Tottenham Court Road.	661 per hour, of which 487 are omnibuses, being equal to about 74 per cent. of the total number of vehicles.	

In Liverpool the traffic tonnage and annual cost for maintenance per square yard of the different descriptions of pavement, and of the pitched pavements in particular, have been recorded since 1872, the material being from different sources.

The following record (Table LXII.) of street traffic is the form adopted in London.

In addition to the amount of traffic which a carriageway pavement has to sustain, the relative safety of the different descriptions of pavements should be recorded, while the damage done to horses, vehicles, and harness, by reason of an irregular surface or a state of disrepair, must not be lost sight of. It is generally admitted that a pavement with a smooth, regular surface means longer life to horses and vehicles, the road surface does not wear out so quickly, and the cost of transit is considerably reduced, but it is noticeable that the better the class and condition of the pavements the

TABLE LXII.

Record Table of Street Traffic.

Name of Street...............Class of Pavement...............State of Repair...............Width between Curbs...............ft...............ins.

Gradient 1 in...............Period under observation from (*time and date*)...............to (*time and date*)...............Name of Observer...............

	Description of Vehicles.											Exceptional Loads, Weight to be inserted.	Horses falling.	Condition of Road at Time of Fall (Wet, Dry, Greasy, Sloppy).
	Omnibuses.			Heavy Dray.	Light Dray.	Heavy Van.	Light Van.	Trades-men's Shop Vans.	Car-riages and Cabs.	Loaded Carts.	Empty Carts.			
	Full.	½ full.	Light.											
	65 cwt.	45 cwt.	35 cwt.	90 cwt.	40 cwt.	70 cwt.	35 cwt.	15 cwt.	15 cwt.	40 cwt.	18 cwt.			
6 a.m., . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...
7 ,, . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...
8 ,, . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...
9 ,, . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...
10 ,, . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...
11 ,, . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...
12 ,, . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...
1 p.m., . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...
2 ,, . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...
3 ,, . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4 ,, . .	...	...	...	...	...	...	...	.	...	...	...		...	...
5 ,, . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...
6 ,, . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...
7 ,, . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...
8 p.m., etc., .	...	...	...	...	...	...	...	...	...	...	...	...	...	...

greater the amount of heavy individual loads hauled over them. This is due to the fact, long recognized by surveyors and engineers, that it is essential, in order that some at least of the high-class paving materials may be kept in good condition, that they should be constantly traversed by traffic. This has the effect of keeping them, so to speak, 'alive,' while if the reverse is the case, climatic influences are allowed to play upon them unhindered, and induce decay. Moreover, the cleansing of streets where the traffic is continuous is more frequent, and, therefore, more efficient, which is beneficial to the road surface.

The comparative cost of the best paving materials are given in Table LXIII.; the particulars in each case have been given in the respective chapters on these materials.

TABLE LXIII.

	Cost per sq. yard during the life of the pavement.
Sett or pitched pavements,	1s. 2·19d.
Soft wood ,,	2s. 2·98d.
Hard wood ,,	1s. 6·72d.
Asphalt ,,	2s. 4·18d.

CHAPTER XVI.

FOOTWAYS—PAVING MATERIALS FOR FOOTPATHS, KERBS, CHANNELS, GULLIES.

457. Footways.—The width of footways is generally regulated by the width of the carriageway and the amount of pedestrian traffic passing along the street. This is a matter which should receive considerable attention, so that the relative proportions of one to the other may be in accordance with local requirements, as well as with the general appearance of the street. In ordinary circumstances the footway on each side of a carriageway may be advantageously made ⅙th to ⅕th of the total width of the roadway; the fall from the heel of the path to the kerb may vary from ⅛ inch to ¼ inch per foot, according to the description of material used for paving the footpath. For concrete and asphalt the former fall is sufficient, while the natural stones, bricks, and such-like materials are laid with the latter fall or a gradient of 1 in 48.

The materials of which the wearing surface of footways are made vary considerably, and these afford an opportunity for selecting a suitable paving under different conditions of traffic and situation.

458. Qualities which Paving Materials should possess.—The qualities which should characterize a good paving material may be enumerated as follows:—It should be durable and smooth without being slippery; it should absorb the minimum quantity of water and dry quickly after rain; it should also be non-abrasive, uniform in texture so as to wear evenly, easily cleansed, have a good appearance, and be economical in first cost.

The different kinds of material used which are suitable for this purpose are divided into natural stones and artificial stones, or compositions, the following being the principal descriptions employed:—

1. Natural stones, such as Caithness, Yorkshire flagging, and Arbroath pavement.
2. Asphalt, standard and Trinidad, tar paving.
3. Concrete, in monolith and slabs.
4. Composite flags.
5. Bricks and tiles.

The selection of the best material which will answer the requirements in regard to situation and heavy pedestrian traffic should be made only after actual trial, although many of the properties necessary may be previously ascertained, such as the absorbent powers, the specific gravity, and the resistance to abrasion.

A good foundation is indispensable for footways, and when a natural one does not exist, an artificial foundation must be provided. This may be accomplished by the use of furnace clinkers or cinders, broken bricks, tiles, and freestone shivers, with the addition of proper drainage to dispose of any water penetrating to the underbed of the footway. By using a suitable material for the foundations (which should be well rolled), the cracking or damage of the wearing surface, which is often attributed to bad workmanship in laying it, will be obviated or at least reduced to a minimum.

459. Natural Stones—*Caithness Flags.*—Of the natural stones used for paving a footway, Caithness flags are considered the best. This description of pavement is very durable, wears evenly over the whole surface, and does not become slippery; it is impervious to wet, and dries quickly after rain; it is not affected by frost, and dust and dirt do not adhere to it readily. It is a very dense material, does not laminate, and can be easily taken up, turned, and re-used when worn. This description of paving varies from 1½ inch to 2 inches in thickness, as shown in fig. 134; the joints are generally sawn, which facilitates the expeditious laying of the pavement. The first cost is against its general adoption in many of the large towns, although it is extensively used in busy manufacturing centres such as Liverpool, Birmingham, South Shields, and Sunderland; it is also much used in Scotland, especially in Edinburgh, Glasgow, and Aberdeen.

Yorkshire Flags.—These possess many of the essentials of a good paving material for footways, and are generally made from 2½ inches to 3 inches in thickness. This description of paving does not wear smoothly, consequently it affords a good foothold. It is easily worked to curves or irregular lines, and has an agreeable appearance. Like Caithness flags, they can be lifted, re-dressed, and used again; but the great drawback to Yorkshire flags is that they wear unequally, and are liable to laminate under atmospheric influences, especially in frosty weather.

Arbroath Pavement.—This description of paving material is much used in Scotland, especially in the larger cities and towns. It varies from 2½ inches to 3 inches in thickness, is of an agreeable appearance, wears evenly, and can be used again by being re-dressed. The joints are sawn square to the full thickness, which ensures quick and accurate laying.

Other natural stones of the sandstone and limestone order are employed locally, such as Pennant, Purbeck, Blue lias, Devonian limestone and Lazonby; the latter sandstone, from the Penrith district, is very durable, and affords a good foothold, and the selected sorts wear very evenly. Granite slabs, which were extensively used years ago, are now seldom laid. They are very durable, but the multiplicity of joints is a serious defect, and they also become extremely slippery. The slabs are difficult to dress and are very expensive.

Laying Natural Stone.—The different kinds of paving material for footways referred to should be bedded on the foundation already mentioned, with a layer of lime mortar evenly and truly laid with square joints, which should be flushed up with good mortar.

Life of Paving.—The life of these footway paving materials will of course vary according to the amount of pedestrian traffic. Caithness flags in many instances have been down for fifty years, but from twenty-five to thirty years may be considered about the maximum duration for them. It has been stated that in some instances Yorkshire flagging had only a life of from six to seven years, but this was probably owing to a soft description of stone being used.

460. Composite Paving.—*Asphaltic Footway Pavements.*—The method of laying rock and Trinidad asphalt is very similar to that for carriageways, which has been already described, the only difference being that the thickness is reduced to ¾ inch and 1 inch respectively. Owing to the creeping tendency on footways situated on an incline, the former description of asphalts, principally Limmer, Val de Travers, and Seyssel, the first possibly being the best known, cannot be laid with advantage owing to the tendency to crack through this cause. Foundations for this description of footway paving should be of Portland cement concrete, six to one, and laid from 3 inches to 4 inches in thickness. The surface of the concrete is smoothed over, and three to four days must be allowed for it to set before commencing the spreading of the asphalt.

461. *Tar Concrete Pavement.*—This description of paving material is much used in suburban districts where the pedestrian traffic is light. The methods of manufacture and laying vary considerably in the different districts in which it is employed.

The process is somewhat similar to that of making and laying tar macadam, only the aggregate used is much smaller, generally consisting of fine gravel or stone chippings. The stones vary in size from 1½-inch to ¼-inch gauge, and these are dried by being heated, a boiling composition being added in the following proportions:—

12 gallons of tar.
½ cwt. of pitch.
2 gallons creosote oil.
1 ton of screened material.

This mixture is spread in layers, the largest-sized stones being laid on the prepared foundation and finished with the smallest class of material, each layer being compressed by means of a hand-roller, weighing about half a ton, until a uniform surface is obtained.

For really good work the material forming the aggregate should be capable of absorbing a certain amount of the tar composition, for which purpose mountain limestone or Kentish rag is the best. If hard material, such as granite or whinstone, be used, a bumpy surface may result, which, besides impeding the drainage, makes a very unpleasant path to walk on. As in the case of tar macadam and asphalt pavements generally, tar concrete paving must be carried out in dry weather, preferably in the spring or autumn, while the success of the pavement will depend to a great extent on the efficient drainage of the underbed.

To add to the appearance of a tar concrete paving, white spar or stone dust is thrown over the surface, rolled in and finished with sand. Like tar macadam for roadways, tar concrete improves by being stored for a few months previous to using it. When applied under these circumstances, the mixture is 'freshened' by the addition of a small quantity of refined tar.

Apart from ordinary repairs, the surface of a tar concrete footway requires dressing occasionally. This is performed in dry weather by applying hot tar to the surface, which must be previously swept clean, and a layer of sharp sand spread over it. This will prevent the dressing adhering to the feet of pedestrians, and at the same time form a skin and add materially to the life of the paving. The tar for this purpose, as well as for the concrete mixture, should be well seasoned or refined to ensure good results.

Tar concrete paving is not suited for main thoroughfares in populous centres, the most suitable localities being suburban districts and small towns. The use of artificial stone for paving footways dates back about thirty years.

462. Concrete Paving.—It may be carried out in monolith, and also by laying prepared slabs. They are for the most part practically the same, being formed of gravel, broken stone, or granite reduced to the size of pea gravel, or $\frac{3}{16}$ inch in diameter, mixed with Portland cement in the proportion of three of granite to one of cement.

There is an endless variety of this description of paving material made by different firms.

During the last few years, this class of paving material for footways has come into very extensive use, and most of these are manufactured and laid in a similar manner, with but minor variations.

Pavements laid in situ.—Pavements of this description, such as Stuart's granolithic, Empire, and Victoria, require a good firm foundation, as on this, to a great extent, depends the future of the wearing surface or its being able to withstand the pressure of the pedestrian traffic.

The ground is excavated to a depth of 5 inches below the finished level, and upon this is spread a layer about 4 inches in thickness of cinders, gravel, furnace clinkers, broken tiles and bricks, freestone shivers, or other suitable material. This layer must be properly punned or rolled and the interstices filled up, and the upper surface should be 2 inches below the finished surface of the footway.

The pavement is divided into panels or bays, varying in width from 4 to 6 feet, separated by strips of wood. Narrow panels are necessary to prevent the concrete forming cracks transversely when a sudden change of temperature takes place, which has been the cause of this description of paving being thrown out of position when laid *in situ* with panels of greater width.

The strip of wood is at times retained, but in most instances it is removed, the alternate bays or panels being constructed after those first laid are set and have become thoroughly hard. A strip of roofing felt is at times introduced between the joints to provide for expansion, and serves the purpose admirably, provided the panels are not laid of a greater width than 3 to 3½ feet.

After the area is divided into bays, a layer of concrete (4 to 1), 1½ inch to 2 inches thick, is spread and well punned with flat-headed beaters, and before this first layer is set a finishing coat of fine concrete, consisting of ten parts of granite chippings, thoroughly washed, to one part of Portland cement, is spread. The concrete should be carefully mixed, water being added only in small quantities. The finishing coat is spread to about a thickness of an inch, and well worked to remove all cavities, the surface being then trowelled off smooth. Every alternate bay is finished and allowed to set properly before the intermediate panels are commenced. The wearing surface, when partially set, is finished with an imprint hand-roller, either making indents or forming a grooved or corduroy surface, for the purpose of giving a better foothold. With some descriptions of concrete paving such means of preventing slipperiness is not considered necessary, except on inclines, while at the same time some authorities state that it interferes with the wearing surface of the paving.

Traffic should not be permitted on the pavement till the concrete has thoroughly set and become hard, and till then the pedestrian traffic should be diverted or accommodated by placing a temporary platform of wood over the surface. In hot, dry weather the concrete, after being laid, should be protected by spreading sand over the surface, or by placing old cement bags, kept thoroughly wet, on the pavement.

One objection to monolith pavement for footways is that repairs are difficult to make should the covering be lifted for the purpose of laying or renewing pipes. The greatest objection is the prolonged disturbance of the pedestrian traffic during the time it is being laid and is setting, a serious matter in a busy thoroughfare, where shops abut on the footway. This class of pavement should only be laid in good weather, heavy rain or the prevalence of frost being detrimental to its durability.

463. Concrete Slabs.—In consequence of the objections in connection with monolith pavements, concrete slabs, which are free from the defects mentioned, are now frequently used. Victoria stone, hard York stone, and many other descriptions of concrete slabs are made in a similar manner, and are formed in wooden moulds lined with metal, to facilitate their being removed when set. They are composed of broken stone, gravel, and sand mixed with Portland cement and water; in many cases a solution of silicate of soda is added. They are made in various sizes, the most useful dimensions for paving work being 30 inches in length and 24 inches in width, and 24 inches square by 2 inches thick. The process of making the slabs hard and dense is carried out by most firms by subjecting the concrete to great pressure in the moulds.

The aggregate, consisting preferably of ⅜-inch granite chippings, washed to remove the associated dust, is thoroughly mixed in a dry state with Portland cement, the proportion adopted being three of the former to one of the latter. After this has been accomplished, water is added in a careful manner, and the whole is mixed until thoroughly incorporated. The 'compo' is then placed in moulds and worked at the corners and sides with a trowel to ensure clean, accurate arrisses all round the slab, and finished to a smooth surface. The moulds containing the concrete are in some processes subjected to a mechanical movement of a jolting nature, which motion obviates the formation of air cavities.

The slabs are removed from the moulds at the expiration of two days, and stored for seven to nine days in order to become air-dried, and then, should the process be adopted, immersed in a bath containing a solution of silicate of soda. After being so treated for a week or fourteen days, according to the capacity of absorption, the slabs are stacked in the open for some months to season, previous to being used.

Many manufacturers of these concrete slabs use only one class of granite chippings, which is produced principally at the quarries in Aberdeenshire, Bonawe, Furness, Leicester, Guernsey, and Quenast (Belgium).

Adamant paving slabs are made of finely crushed Aberdeen granite and the finest Portland cement. The concrete, when properly mixed, is placed in moulds and then subjected to hydraulic pressure. This effectually disposes of both air cavities and moisture, the result being a dense, non-porous, and homogeneous stone or slab, which can be handled immediately. By this process the slabs can be manufactured and laid in the course of a few days. The ordinary sizes made are 3 feet x 2 feet, 2½ feet x 2 feet, and 2 feet square by 2 inches in thickness. These slabs for paving footways are largely used in Aberdeen, Edinburgh, and many English cities and towns.

Paving slabs made from the clinker produced by refuse destructors, and mixed with Portland cement, are extensively used in certain towns. They are not, however, so durable as concrete paving made with granite chippings, but they form a cheap material which is quite suitable for footways in subsidiary streets. Pavements formed with concrete slabs are easily cleansed, and being non-absorbent, dry quickly after rain, while they can be expeditiously laid, and they wear evenly.

464. *Concrete Slabs from Refuse Clinker—Footways.*—A number of towns throughout the country now manufacture this form of paving slab, and the method adopted at Cheltenham is as follows * :—The slabs are made under hydraulic pressure, the plant having been supplied by Messrs. Musker, of Liverpool. The town refuse forms the fuel for generating steam to drive the machinery, and the clinker from the destructor is the aggregate used in making the concrete for the slabs. The hardest of the clinker is selected, and after being ground in a mortar mill to pea size, Portland cement is added in the proportion of one of cement to three of clinker, the necessary quantity of water being applied during the mixing. This forms the material for the body of the slab, the wearing surface being made of concrete composed of three parts fine granite chippings to one part Portland cement. The total thickness of the slab is 2½ inches, and the granite face is about ¾ of an inch thick. The concrete material is placed in the mould of the machine, and after being subjected to a hydraulic pressure of over a ton per square inch for a minute or so, is delivered in slabs on to carrying boards, on which they are removed to a drying shed close by. After lying on the boards for a week or so, the slabs are stacked in the open and allowed to mature for at least six months before being removed for use. A stock of about 10,000 square yards is always kept in hand. The cost of manufacture works out at from 2s. to 2s. 3d. per square yard, including all charges for renewals, interest and repayment on loan account, and working expenses. The plant also produces concrete kerbs 12 inches by 5 feet long, having a bevelled edge, at an exclusive cost of about 6d. per lineal foot. The slabs are used extensively for the paving of the public footpaths in the town (about 40,000 square yards having been laid), and although they have only been laid a comparatively short time, there is every reason to believe that they will make a durable and economical pavement.

The *modus operandi* is as follows :—Tests having been previously made of the exact amount of material which is necessary to produce under a maximum pressure a block of the size required, the prepared material is tipped from a measuring box into a mould which slides into position in the centre of the machine between plungers fixed to the top and bottom plates. The pressure is applied by means of a twin-rocking pump with cylinders of different sizes, 1⅝ inch and ⅝ inch respectively. Each pump is provided with two safety valves, which blow off at any desired maximum pressure, usually at six and fifty tons respectively. By this method the larger pump brings the material to its work quickly, as it rises by ¼-inch plunges, and when it approaches the necessary density a few strokes of the high-pressure pump is sufficient to complete the operation. It is then only necessary that the valve should be opened by a simple movement of a lever, and the whole of the water used flows back into the cistern and is used over and over again, thus doing away with an accumulator and other connections usually necessary. The whole press is so portable and self-contained that it only occupies a space of about 3 feet square at the base, and 18 inches extra on two sides of the table for guides to enable the blocks to be easily withdrawn.

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* *The Street*, 28th July 1906.

At Battersea, where 64,000 square yards of such slabs have been laid down during the past two or three years, the slab itself is made to a thickness of only 1¾ inch, the face being composed of ¾ inch of granite grit and Portland cement in equal proportions. Several kinds of granite grit have been experimented with, and experience has shown that Norwegian washed grit, not exceeding ⅛ inch in size, gives the best results. The cost of making and stacking, including all charges, is given here as less than 2s. per square yard. At Southampton, where clinker slabs have been laid for nine years, the price is given as from 2s. 6d. to 3s. per square yard, while Bristol gives the price as 5s. 2d., a figure which is no doubt inclusive of foundation.

The cost of paving for footways varies considerably, depending on the locality and the description of material used. York stone varies from 5s. to 12s., concrete slabs 4s. 11d. to 7s. 7d., and clinker slabs, as shown above, from 2s. to 5s. 2d. per square yard respectively.

From data obtained from a number of towns and boroughs, and compiled by the city surveyor of Manchester, on artificial stone paving in comparison with natural stone, it appears that the great bulk of the towns applied to have adopted artificial stone which costs less than the natural, though naturally the price varies considerably with the locality and the make and thickness of the stone. Artificial stone, however, is more subject to breakage when lifted and relaid, which is partly accounted for by the close joints and the brittle nature of the concrete. The average waste on this account is estimated at about 3 per cent. "The risk of breakage," says Mr. de Courcy Meade, "can be diminished by jointing the artificial stone with lime mortar instead of cement. The practice of the borough surveyor of Fulham is to test every flag by placing it on supports 2 feet apart, and subjecting it to a weight of one ton placed in the centre of the flag between the supports. Artificial slabs are not found to be more injuriously affected by severe frosts than natural stone. If either artificial or natural paving is laid on a wet foundation, the frost will penetrate the damp subsoil, and lift and probably crack the material."*

465. Brick or Tile Paving.—Bricks or tiles to be of any value as a footway paving require to be of hard vitrified stoneware. They do not form an ideal paving material, but are greatly used in many towns in the Midland counties of England.

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* Vide *Surveyor*, 3rd and 10th March 1905.

Blue Staffordshire and Buckley bricks, measuring about 10 inches × 5 inches × 2 inches deep, with a chequered or diamond pattern surface, are those most largely used; they make a durable pavement when laid on a foundation of concrete.

Owing to the numerous joints, this paving is difficult to cleanse, and when worn becomes slippery and uneven. The appearance of brick paving is not in its favour; it does not make a pleasant surface to walk upon, but it is well suited for many footways in the streets of manufacturing towns. The bricks can be lifted and relaid at small cost, which is a point in its favour, especially where the footways are often disturbed in introducing or repairing service pipes and house connections. The life of this paving is estimated at various periods up to thirty years.

Brick paving is much used in the United States as a material for covering footways in the towns, where it is extensively employed for carriageway pavements.

Sanitary Tiles.—Sanitary tiles for footways are made in 8-inch squares or 5-inch hexagons, and 2½ inches thick; they may be laid on a 3-inch concrete foundation, or on a bed of gravel well punned and a layer of sand. The blocks are laid closely together, the joints being closed by compression under traffic. It affords a safe foothold for pedestrians, is smooth and even, and does not become slippery through wear. It is practically waterproof, dries quickly after rain, and can be quickly and easily repaired in all conditions of weather. It is stated to be durable and economical.

466. Footways situated in country districts are generally formed with from 4 inches to 6 inches of coarse gravel or freestone chips, and finished with fine gravel or the screenings from a stone-breaking machine. Furnace cinders are also used in districts where they can be easily obtained. This description of footway has been treated in Chapter VIII.; it appears to serve the purpose very well when kept in proper repair. For suburban districts, and in small provincial towns, tar paving may be advantageously employed where suitable materials can be obtained.

467. Kerbs.—A kerb should be of a sufficient height, varying from 3 inches to 8 inches, except at crossings. Kerbstones of less height, apart from allowing water to flow over the footway, would render it possible for vehicles to drive on to them, while a greater height than 7 inches or 8 inches is inconvenient for foot passengers.

The materials used for forming kerbs are of various descriptions, but, for first-class thoroughfares having much traffic, granite, syenite, and whinstone are by far the most satisfactory for this purpose, and although expensive in first cost, are ultimately much more economical. The other materials used are sandstone, cement, concrete, vitrified fireclay blocks, cast and wrought iron.

Granite, syenite, or whinstone kerbs are made in various sizes; where concrete is used for the foundation they are generally laid on their flat, as shown in figs. 134 and 138, the usual size being 12 inches by 8 inches. For the most part kerbs are made 6 inches to 8 inches by 12 inches; they are never made less than 4 inches wide and 9 inches deep, laid on edge, which gives a sufficient hold in the ground for all practical purposes. For comparatively level thoroughfares the blocks are dressed rectangular, but for gradients, or where they are likely to be used as a drag for heavy vehicles, the kerbs are generally splayed off on the front face, as shown at figs. 134 and 138, in order to minimize the grinding action and rough usage likely to arise from the wheels of heavily laden carts and wagons.

Stone kerbs should be dressed with a margin draft along both top edges, and hammer-dressed about 6 inches on the face and 3 inches on the back and to the full depth on the ends or jointing surfaces, while the top surface should be similarly treated, or the blocks may be 'nidged' on the top and sides to the depths mentioned. This ensures a clean, decided junction for the paving material of the footway, and presents a smooth and well-defined surface, alongside the channel. The kerb-stones should not be less than 3 feet in length, and when 7 inches or more in width the upper surface ought to be bevelled off, so as to conform with the slope of the footway, and thereby enable rainwater falling on the surface to reach the gutters readily. When deep kerb-stones are employed, as shown at figs. 134, 137, and 138, they are generally bedded on gravel and a layer of sharp, clean sand, and beaten into position by means of a heavy maul or beetle; the gutter side should be further consolidated by using a cramping-iron or iron bar. By such means vacuities are avoided, which, if they existed, would in time tend to overturn the kerb towards the carriageway, and shift it from its upright position. Besides being unsightly, this might necessitate its having to be relaid, entailing additional expenditure. Great care should be exercised in setting out and laying kerbing, both in regard to line and level, as there is nothing more unsightly than badly-laid kerb-stones.

468. Cement Concrete Kerbs.—These can be made in blocks, the concrete being placed in moulds and manipulated by hand or subjected to hydraulic pressure, and laid in position in the same way as stone kerbs, which is preferable, or the blocks may be made *in situ*. In either case the durability of this class of kerb depends on the quality of the gravel or other material used, and the cement. This description of kerb is generally used when the footway is made of concrete, and is only suitable for streets of light or medium traffic, where it is not likely to receive heavy blows or be subjected to the grinding action of the wheels of passing traffic.

469. Fireclay Brick Kerbs.—Kerbs of this class, principally of the blue

Staffordshire description, are laid in many subsidiary streets in provincial towns. Their chief advantage is economy, but, like kerbs made of concrete, they can only be successfully employed in streets of light traffic. Brick kerbs are largely used in the United States and Holland.

470. Cast- and Wrought-Iron Kerbs.—This description of kerb, although of late their use has been more extended, has not been much used in this country. They have, however, been frequently employed on the Continent. So far as the wearing point or edge is concerned they protect the roadway well, but their shape makes them dangerous for pedestrians, owing to their becoming slippery. The cost of these, their shape, and the difficulties in laying them in a uniform manner, appear to have prohibited their use on an extensive scale. Fig. 139 shows a cross section of a cast-iron kerb.

The wrought-iron kerb, or edging, is now extensively used in connection with 'concrete *in situ*' pavements. It serves the purpose very well, and has a smart, well-defined appearance. It is economical, especially where old irregular kerbs exist which require to be renewed. The edging consists of an iron plate 4 inches to 12 inches deep and ½ inch thick, jointed longitudinally where necessary by a cover plate fixed on the footpath side of the kerb. This kerb plate is placed in position, as regards line and level, by means of thin rods of iron 18 inches long, which are inserted in the edging-plate 5 feet apart, and, projecting into the footway, are kept rigidly in position by being attached or anchored to a batch of concrete on the top of the foundation which ultimately forms part of the under layer of the pavement. The top of the iron plate is fixed so that the finished level of the paving material will correspond with it. Fig. 140 shows a cross section of a wrought-iron kerb or edging.

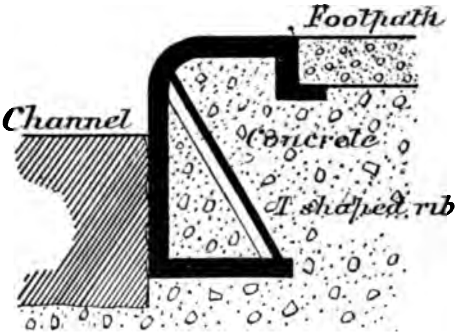


FIG. 139.—Cast-iron kerb.

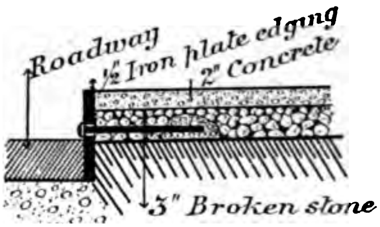


FIG. 140.—Wrought-iron kerb or edging.

471. Channels.—Channels or gutters are necessary in connection with footways and carriageways to receive the surface water from the roadway and convey it towards the gullies; they also protect the kerbs from being undermined, and improve the appearance of the street. The channels are sometimes formed to the same contour as the roadway, as shown in figs. 137 and 138. The general practice, however, when they are constructed with slabs or setts is to lay them level transversely, as shown in fig. 134, to slightly dish the upper surface, or to use 'hollow channel,' as shown in fig. 134. When streets are paved with setts, asphalt, or wood blocks, the same class of material is generally employed to form the channels. Setts and wood blocks of the same size as the ordinary paving material, and in some instances of less size, are laid horizontally, instead of transversely, so as to aid the flow of water alongside the kerb. The gutters are made from 12 inches to 18 inches wide, with from 4 to 6 courses of blocks; at times granite slabs are made use of from 12 inches to 15 inches wide and 6 inches thick, square-dressed on their abutting faces, so as to fit closely together, the upper surface being nidged or tooled. This description of material makes an excellent gutter, but it is somewhat expensive.

Channels should not be laid with a flatter gradient than 1 in 300, and when practicable they ought to be set so as to show 5 inches of the kerb above it, but of course this will depend entirely on the gradient. On practically level carriageways the channel will vary from 3 inches to 7 inches below the upper surface of the kerb in order to give sufficient fall for the surface water to drain rapidly towards the gullies. Figs. 137 and 138 show the arrangement of channels for different descriptions of carriageway pavements.

At crossings or intersections of streets the channels are raised so as to be nearly on a level with the kerb, which is a great convenience to pedestrians. This arrangement, under certain circumstances, necessitates extra gullies, but it is a much more satisfactory method of overcoming the difficulty, compared with that of employing rectangular iron conduits (which have been much used in the past), besides being less objectionable as regards interference with vehicular traffic.

472. **Gullies.**—These are placed at certain intervals along the gutters, and are connected with the sewers. The distance apart will vary considerably, according to the gradient of the carriageway, the nature of the traffic, and the capacity of the gully itself. They may be made of brick, stoneware, or iron, and covered with gratings of cast or wrought iron. The essential points which a street gully should possess are:—

1. The area of open grating must be sufficient to cope with heavy and sudden rainfalls.

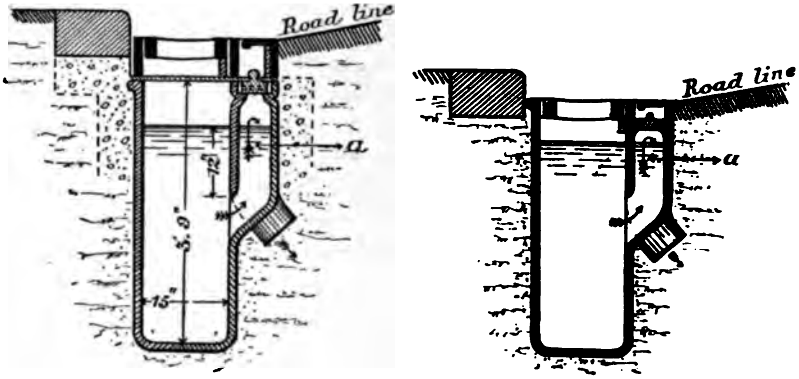
2. The grating must be so constructed as to permit of the least possible obstruction or choking on its surface by road detritus, paper, straw, or leaves.

3. The gully must be of adequate capacity to retain the road detritus below the outlet pipe and so prevent its entrance into the sewer.

4. It should have a deep-water seal or trap to prevent the escape of

sewer gas, be easily cleaned out, and so constructed that it can be readily cleared by suitable means should a stoppage occur.

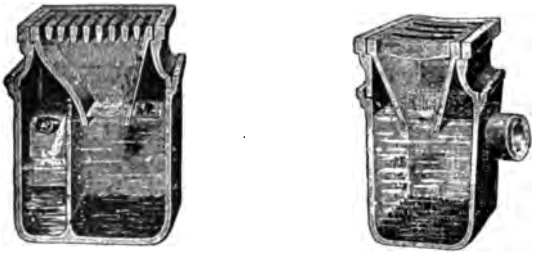
5. The grating should be such that it will form the least possible obstruction to the traffic, and on macadamized roads the outlet pipe of the gully ought to be placed at such a depth below the surface of the roadway that it will be secure from injury by heavily laden vehicles and steam rollers.



FIGS. 141, 142.—Sykes' gully traps.

6. It should be constructed of materials not likely to be damaged by the tools employed for removing the detritus, and it should be made strong and thoroughly water-tight.

In some cases the gully is composed of granite, stoneware or cast iron, or cast iron only, while the majority are made chiefly in stoneware. An instance of the first type is that of Sykes' (fig. 141); of the second, Crosta's (fig. 143, 144), both of which are now well known and all extensively used, while those which are for the most part manufactured in stoneware include Doulton's, Sykes' (fig. 142), and various others, all of which are of considerable merit.



FIGS. 143 and 144.—Ames's Crosta's gully trap.

In many localities, under certain conditions, large gully pits are constructed so as to retain a considerable quantity of road detritus. These, for the most part, are placed in streets situated on a gradient, and are generally built of brick and lined with cement or asphalt, while at times they are provided with double gratings; the size of the pit may be 3 feet by 1½ feet, and from 3 feet to 4 feet deep. Fig. 145 shows one of these gully pits as used in the city of Liverpool. It is constructed of brickwork lined with cement, the bottom being of York or other suitable flag, while the tongue is made of similar stone.

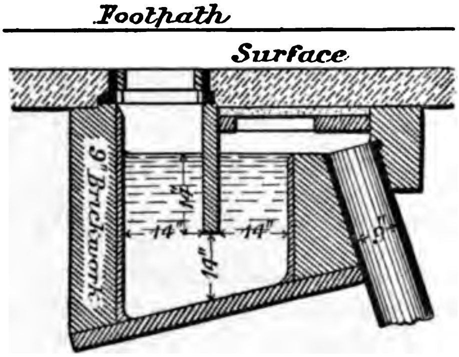


Fig. 145.—Section of gully pit used in Liverpool.

CHAPTER XVII.

TESTING THE SURFACES OF CARRIAGEWAYS.

473. The testing of the surface of carriageways and macadamized roads for unevenness may by some be regarded as an unnecessary refinement in connection with road engineering. The introduction of the viagraph has, however, proved of great value in making autographic records of road surfaces, and in enabling comparisons to be made of the unevenness of different descriptions of pavements. The records of the viagraph are of a practical and definite nature, and indicate with exactitude the condition of the surface of any roadway. The indices of unevenness and the viagrams, or automatically produced records, are of a permanent nature, which, being numbered and filed, are valuable for future reference.

The expression, 'like a turnpike road,' made use of during and since the coaching days when indicating the condition of a road, in comparison with roads generally, signified an excellent surface. These expressions and others, such as in 'a good' or 'a bad' condition, employed by such experimenters as Macneill, Morin, Dupuit, and Michelin in their researches on the resistance of road vehicles to traction, have no definite or satisfactory meaning. Any expression formed upon casual inspection is at the best of a transitory nature, and totally unsatisfactory in connection with scientific research.

This desideratum is overcome by the use of the viagraph, which records the exact nature of the road surface, thus supplying a definition of its condition, beyond cavil and dispute, hitherto impossible. The method of laying any particular description of pavement and the system of maintaining macadamized roads vary considerably in different parts of the country, and that which, from visual examination, appears to be a fairly well-finished piece of work may show, by the automatic records, many inherent defects. For instance, on asphaltic pavements the contour may present a series of long, wavy undulations.

On wood pavements the irregularity or unevenness of surface is brought about by various causes, such as uneven or yielding foundations, badly cut blocks, defective laying, and wide and irregular joints. The latter is

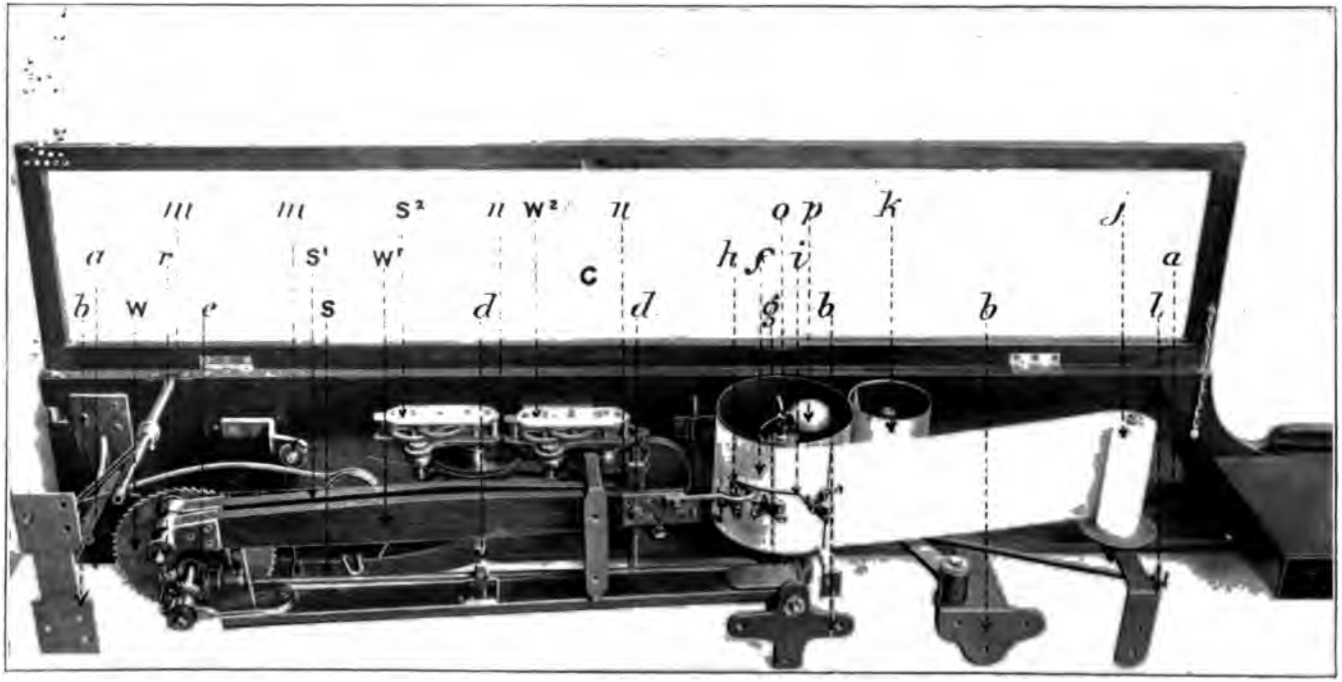


Fig. 116. - Showing mechanism of Viagraph.

[*To face p.* 435.

particularly the defect met with in sett pavements. In the case of macadam, the use of irregularly sized road stones is clearly defined by the viagraph; while improper spreading of the material and the application of too much binding are factors of great importance in road maintenance. These defects are all easily detected from the records of this road surface testing instrument.

The tests are comparative, and the particular road surface tested will vary from time to time through the continual wear incidental to all descriptions of carriageways.

474. The viagraph, as might be inferred, consists of a straight edge applied continuously to the road surface, along which it may be drawn at a foot pace. The instrument is in form like a sled with straight runners 12 feet long, *a* (fig. 146), and spaced 9 inches apart, held rigidly together by metal struts *b*. To render the instrument more portable when not in use, it can be reduced to half its length by folding the after-runners forward on hinges provided for the purpose, at the centre of the frame. The profiling and the recording mechanism are mounted on the frame between the runners, and protected by a hinged glass cover C. The contact working parts of the instrument, namely the wheel W and slider S, along with their levers W^1 and S^1, which are fixed on a horizontal pin at *r*, are so arranged that they rise and fall, independently of the frame, over the unevennesses of the road-surface tested, thereby transmitting the movements through the vertical links *d* and the levers to the profiling pens. These working parts are kept in close contact with the road by means of suitable springs. The serrated steel wheel W, 6 inches in diameter, and designated the road wheel, gives, in traversing a road, the necessary movement for operating the mechanism by means of two mitre wheels *e*, connected to the profile drum *f*, which is rotated by a worm wheel *g*. The gearing is so arranged that the periphery speed of the profile drum *f* is to that of the road wheel as 1 to 96. The slider part of the instrument S, made of hardened steel, is curved to a circle corresponding with that of a carriage wheel of average size, namely, 40 inches in diameter. To this slider may be attached a variety of curved surfaces representing segments of wheels of different diameters and widths of tyres.

At the ends of the levers of these contact working parts stylographic pens *h* are fixed, carried on spindles capable of being adjusted to any suitable height or angle, which transmit to the strip of paper the exact motions of the wheel and slider in passing over irregularities on the surface of a road. Another pen *i*, attached to a spindle, which is fixed to a bracket on the side of the frame, and capable of vertical adjustment, draws a datum line corresponding to the under edge of the runners in relation to the movements of the wheel and slider. These pens are kept in active contact on the surface of the paper on the profile drum by means of spiral springs. The paper is supplied from a stock roll *j*, and, passing round the profile drum *f*, is wound on to the receiving drum *k*, which is rotated by friction with the former, and capable of adjustment by means of a tension spring and screw *l*. A spring pressing on the stock roll maintains the paper at its proper tension as it is drawn off.

The result is an autographic record of the road traversed, showing in a very clear and decided manner the irregularities of the surface, from which can be ascertained the depths of the hollows and irregularities.

In addition to the profiles, the sum of all the depths of unevenness passed over is recorded by the decimal counters W^2 and S^2, and indicated in feet per mile, which constitutes the numerical index of unevenness, assuming the portion of road-surface tested to be of a typical character. The wide range of these indications, varying as they do from a few feet to over 200 feet per mile, gives ample means of clearly defining the condition and character of the road under examination. The arrangements by which these counters are worked is by means of short pieces of wire and chain attached to the wheel and slider respectively, and, working over pulleys *m*, pass partly round the recording mechanism. The latter consists of ratchet wheels *n*, 0·05 inch pitch, with triple differential pawls; this, therefore, practically means that irregularities to the extent of $\frac{1}{60}$th part of an inch are registered by the decimal counters.

In comparing the unevenness of one road with another it is obviously necessary that the same length of each road be taken as a unit. For that purpose a length of 88 yards, being $\frac{1}{20}$th part of a mile, is convenient, and is measured off automatically in using the instrument by an apparatus fixed inside the profile drum. This part of the mechanism consists of a two-armed bracket *o*, carried loosely at the top of the fixed spindle on which the profile drum rotates, but capable of being fixed at any horizontal position by a wing-nut. On one end of the arm is a bell *p*, and on the other a trigger with three teeth which engage successively with the single tooth on the inside of the profile drum, and when the last contact is made the bell rings, indicating that the end of the unit has been reached. Suitable hooks are provided for keeping the wheel and slider clear of the ground when not in use.

475. The adjustment of the working parts of the viagraph, before taking a profile, is readily accomplished by placing it on a perfectly level surface, and fixing the datum pen at a convenient height on the paper, the others, namely, the wheel and slider pens, being fixed so as to correspond with the datum line. These are practically permanent adjustments, but it is advisable to check the relative positions of the pen points occasionally. These pens, necessarily of short length, are supplied with an ink reservoir at one end, and can be adjusted to any position vertically, on spindles provided with set screws. The pens are kept in contact with the paper by

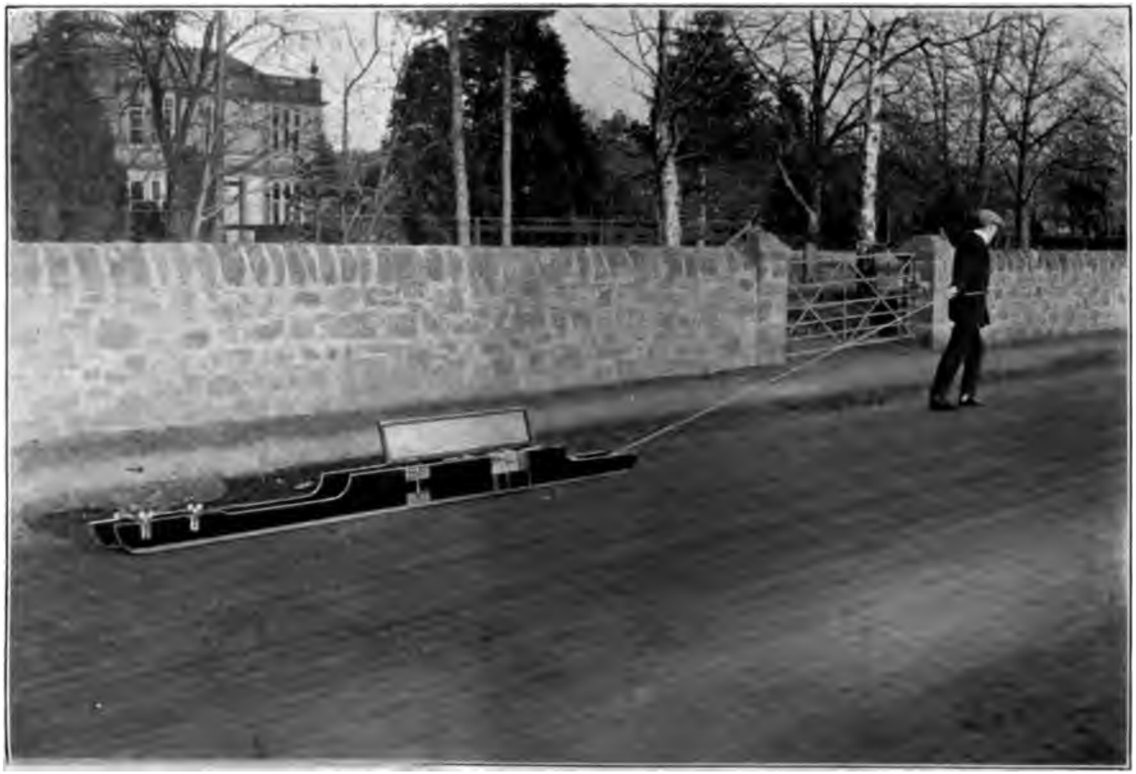


Fig. 147.— Viagraph in use on a Macadamized Road. [*To face p.* 437.

means of spiral springs. In fixing the relative position of the wheel and slider pens, horizontally, it is necessary to place the points $\frac{1}{16}$ of an inch apart, corresponding with the lead of the slider over the road wheel, which also admits of the pen points clearing each other when in use. On a very good road surface, however, the two profiles are inclined to run into one curve, and when this is the case it is advisable to place them $\frac{1}{8}$ of an inch apart on the paper, making a note of the fact.

When the unit length of 88 yards has been traversed, 33 inches of paper will have been drawn through, the result being a profile of the road surface, or, as it is termed, a viagram. The apparatus for measuring the distance of 88 yards is set by placing the pointer on the bracket opposite the single tooth on the inside of the drum, and the trigger so that its position is at right angles to the bracket. The bell arrangement requires to be reset each time the instrument is made use of. Before taking a profile, a vertical line should be drawn on the paper and numbered for future reference. The figures on the decimal counters should also be noted before and after testing a unit length of road, and carefully recorded in a note-book, with the viagram number and a description of the particular part of the road tested. The scale of the profile is $\frac{1}{8}$ of an inch to 1 foot horizontally, and full size vertically. The profile of a road surface, or viagram, together with the numerical indices of unevenness, give a fair estimate of the quality or nature of a road at the point tested. Fig. 147 shows the viagraph in use on a macadamized road.

The slider profile and index of unevenness are those generally made use of in comparing one road or street with another, the road wheel under these conditions acting principally for the purpose of operating the gearing in connection with the profile drum and measuring the unit length of road under test. This arrangement applies particularly to jointless pavements, when the indices of unevenness of slider and wheel are, in most instances, practically the same. On paved carriageways and on macadamized roads, however, the wheel index of unevenness rises in proportion according to the width and openness of the joints on the former; while the wheel serves a good purpose in detecting when an undue amount of binding material is present in macadamized roads. The index of unevenness under such circumstances is abnormally high compared with a road the coating of which has been consolidated with binding sufficient only to ensure cohesion.

476. To test the surface of a road properly for unevenness, and so arrive at a fair average, it is necessary to take three or more profiles, parallel to each other, depending on the width of the thoroughfare. It is also advisable, in many instances, to take the profiles in a continuous manner to ascertain how much the irregularity of the surface varies on different portions of the carriageway, such as on level parts and on gradients.

In testing macadamized roads under the author's jurisdiction, it is the general practice to take two or more continuous viagrams parallel to each other for a distance of half a mile, noting the figures and marking the viagram as each unit length is reached. By this means reliable data are obtained and a fair average arrived at, which is preferable to testing an isolated portion of a road. These tests should be carried out periodically to show the comparative wear or unevenness during a given period.

When the tonnage passing over a road can be ascertained, even approximately, the relative wear so far as unevenness is concerned, of the different kinds of road stones, forms a very interesting item on the subject of road management. This arrangement applies especially to paved streets or carriageways in towns.

The irregularity or unevenness of a road surface may arise from various causes apart from actual wear, trench work and yielding foundations being factors which should be taken into consideration in making comparisons.

477. The viagraph was originally introduced by the inventor* to compare Irish roads with those on this side of the channel, but the main points now claimed are as follows:—

1. "To ascertain the condition of roads at a distance without a personal inspection. Any intelligent man or boy can carry out viagraph testing.

2. "To obtain records of the surface of any road from time to time under various systems of maintenance, and to compare the relative merits of such systems.

3. "To make comparisons of roads in other districts in order to emphasize the need of more expenditure or a different treatment in the surveyor's own district.

4. "To keep a check on road surveyors or inspectors, by causing diagrams to be made of the road surfaces in their respective districts.

5. "In actions at law, when the state of the road surface is in question, to bring forward definite evidence of its exact condition.

6. "In cases of disputes with contractors, to produce graphic evidence of the state of the road surface in support of the surveyor's contention.

7. "To make contracts for the repair of roads more definite, by the insertion of a clause to the effect that, when tested by the viagraph, the surface must not show any rut or depression of more than — inches, nor any unevenness of more than — feet per mile.

8. "To assist in settling claims made for maintenance between County Councils and other local authorities, by producing before the arbitrator evidence of the condition of any road in question.

9. "To controvert complaints, if unjust, that may be made, either in the Press or otherwise, of the bad condition of any road; or to ascertain if the complaint is sufficiently well-founded to need attention."

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* Mr. J. Brown, F.R.S., Longhurst, Dunmurry, Belfast. Makers—Glenfield & Kennedy, Kilmarnock.

It must be remembered that these tests are for smoothness or uniformity of surface, foothold not being taken into consideration.

478. For the purpose of comparison it will be advantageous to detail the different descriptions of pavement according to the excellence of surface, within a reasonable time after these have been constructed or repaired. Particulars are, therefore, given of the jointless or asphalt pavements, including tar macadam, in the first instance, then examples of wood and sett pavements. Macadamized roads of the ordinary construction follow, and these, in many instances, show great divergence from uniformity.

The less reading or the lower the figures and the nearer the numerical indices of the slider and wheel agree, the more perfect is the surface of the street so far as regularity or smoothness is concerned. The method of constructing pavements, especially those formed with joints, and in the case of macadamized roads, differs widely, as may be readily seen in comparing the different results in Table of Viagraph Tests given on pp. 442, 443.

479. **Asphalt Pavements.**—This description of carriageway pavements gives practically the same numerical index of unevenness for slider and wheel, consequently the former is only given in the following tests on these pavements. Test No. 85,* Cochrane Street, Glasgow. This street was laid with Seyssel in 1900, and gave for the slider an unevenness of 6·7 feet per mile. The profile of this street is shown in Viagram No. 85, and is the best result yet obtained on any class of pavement. The best profile previously obtained was that taken in Broad Sanctuary, London,† which gave an average record for slider of 7·9 feet of unevenness per mile. Many other asphalt pavements have been tested in Glasgow, details of which are given in Table of Viagraph Tests, pp. 442, 433.

In Kirkgate, Leith, laid with Val-de-Travers, after being subjected to heavy and continuous traffic for six years, gave the excellent record of 16·5 feet. In Livingstone Place, Edinburgh, laid with concrete in 1875, the index of unevenness was 34·2 feet.

Tar macadam laid in Race-Course Road, Ayr, April 1899, gave the creditable result of 7·8 feet; while in Wardie Road, Leith, recently laid, the unevenness amounted to 10·9 feet per mile.

480. **Wood Pavements.**—The ratio of the indices for wheel and slider varies considerably in pavements formed with joints, depending not only on the care with which the foundations and blocks are laid, but particularly on the method adopted in forming the joints. This is clearly shown in the table of viagraph tests.

One of the best records obtained for wood pavements was in Trinity

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* These test numbers refer to viagrams in Plate IV.

† The viagraph tests were carried out in London in February 1902, and the majority of the others in November 1902. Other tests have been made from time to time, and the dates of these are notified in the column of remarks in Table LXIV.

Street, Southwark, London. This street was laid with Jarrah in 1898, the joints being $\frac{3}{16}$ of an inch wide, and filled with Portland cement grout. The profile of this street, Viagram No. 22, gave, for slider index, an unevenness of 7·2 feet per mile. The wheel index gave an irregularity of 12·7 feet per mile. The surface of this street, according to the slider index, may be looked upon as excellent, while the wheel index of unevenness, although not by any means inordinate, is decidedly high compared with the record of the slider. In Hampstead Road, St. Pancras, London, laid with Jarrah in 1900, with $\frac{1}{8}$ of an inch joint and grouted with pitch and creosote oil, the index of unevenness, after eliminating depression caused by 'trench crossing,' for slider and wheel were similar, namely, 9 feet per mile. This is a unique result, and clearly indicates that the close pitch joint is practically equal in resistance to the wood blocks forming the pavement, which, by this method of testing road surfaces, proves that the description of joint mentioned is superior to that used in Trinity Street, described above.

In Princes Street, Edinburgh, taken in front of the North British Station Hotel, the unevenness amounted to 11·6 feet for the slider index, the wheel record being 13·8 feet per mile. This part of the street was laid with Karri in 1902, the joints being formed of $\frac{1}{8}$ of an inch studs and grouted with Portland cement mortar. Different streets paved with wood were tested in Edinburgh, the results for unevenness and other details being given in Table LXIV. It is noticeable that all the joints in this class of pavement tested in Edinburgh are formed with $\frac{1}{8}$-inch studs and filled with Portland cement grout.

In Buchanan Street, Glasgow, laid with Jarrah in 1902, the record of unevenness for slider was 19 feet, while in a portion of a similar pavement in the same street, but laid three years previously, the irregularity amounted to 31·1 feet per mile.

In the Strand, London, opposite Charing Cross Post Office, laid with creosoted deal in 1901, the record of unevenness was 20·3 feet for slider and 29·2 feet for wheel per mile.

From time to time, trial sections of different descriptions of wood blocks used for paving purposes have been laid in several cities and towns for comparison in regard to wear and cost.

A striking illustration of this kind is produced in Viagram No. 14, which shows a profile of a portion of High Street, Kensington, London. In this case creosoted deal is laid on either side of a length of American Red Gum wood. These different wood blocks were laid at the same time, September 1899 (since removed and relaid), and consequently had been subjected to the same description and amount of wheel traffic. The creosoted deal gave an average for slider index of 33·4 feet, while that of the American Red Gum showed an unevenness of 75·7 feet per mile. American Red Gum, laid in Whitehall in 1901 (Viagram No. 100), gave, two and a half years later, an unevenness of 52·5 feet for slider and 63·3 feet for wheel per mile. This is excessive for a wood pavement under traffic during so short a period. The comparison is very unfavourable to Red Gum, a class of wood paving extensively made use of some years ago in London; for the most part, however, this description of wood blocks has been lifted and more suitable kinds substituted.

In testing a paved street in Fulham, London, laid with dowelled creosoted deal blocks in 1894, the comparative uniformity of wear or unevenness of surface was exemplified. As the whole pavement was executed at the same time, and consequently subjected to the same amount of traffic, the results are of some interest to municipal engineers and others. The portion of creosoted deal, laid in the usual manner, gave a record of 33·75 feet of unevenness for slider, while on the portion formed with dowelled blocks the irregularity was only 24 feet per mile. This system of wood paving has been extensively employed, as on the Tower Bridge roadway and at the Great Central Railway Terminus, London, and other places, with marked success.

Other wood-paved streets have been tested in various parts of London, particulars of which are given in the Table of Tests, pp. 442, 443.

481. Sanitary Blocks.—This description of pavement, which is practically jointless, was tested in Eaton Square, London, and, contrary to expectation, considering the nature of the material, the results were disappointing. The slider index showed 20·7 and the wheel record 31·5 feet of unevenness per mile. This pavement had not been laid very long previous to the test being made.

482. Sett-Paved Streets. — As might be anticipated, this class of pavement does not give a good example of a smooth or uniform surface as tested by the viagraph, although, from the point of view of actual wear under heavy traffic, certain granites are unequalled.

In order to make the comparisons with other descriptions of paving material as complete as possible, several profiles have been taken of this description of paved street, principally in Glasgow. In Grove Street, laid with square blocks in 1888, the record of unevenness for slider was 36 feet and 43·6 feet of irregularity for the wheel index; while in Cedar Street, laid in 1902, the slider gave 53·7 feet and the wheel 98 feet of unevenness per mile. In Wilson Street, from Brunswick Street towards Candleriggs, laid with granite blocks previous to 1886, a profile of which is shown in Viagram No. 84, the index of unevenness for slider was 104·1 feet, while the wheel record gave the extremely high figure of 206·1 feet, respectively, per mile. The portion of this street tested had been repeatedly opened for laying and repairing water mains and other service pipes, and is probably not a fair example of this class of pavement. It certainly shows, however,

TABLE

Viagraph

Number of Test and Viagram.	Name of Carriageway.	Description of Pavement.	Method of forming Joints.
	Asphalt Pavements—		
85	Cochrane Street, Glasgow, . .	Seyssel.	.. ..
	Wilson ,, ,, . . .	Aleatraz.	.. ..
	Brunswick ,, ,, . .	Limmer.	.. ..
	George Square, ,, . . .	Aleatraz.	.. ..
	Buchanan Street, ,, . . .	,,	.. ..
	Broad Sanctuary, London, . . .	..	.. ..
	Kirkgate, Leith, ...	Val de Travers	.. ..
	Livingstone Place, Edinburgh, . .	Concrete.	.. ..
	Race-Course Road, Ayr, ...	Tar Macadam.	.. ..
	Wardie Road, Leith, ...	,,	.. ..
	St. Vincent Crescent, Glasgow, . .	,,	.. ..
	Wood Pavements—		
22	Trinity Street, Southwark, London, .	Jarrah.	$\frac{3}{16}$ in. filled with P.c. grout.
	Hampstead Road, St. Pancras, ,, .	,,	$\frac{3}{16}$ in. grouted with pitch and creosote oil.
	Princes Street (East End), Edinburgh, .	Karri.	$\frac{1}{2}$ in. studs and P.c. grout.
	Pleasance, ,, .	Jarrah.	,, ,,
	Princes Street (West End), ,, .	Blackbutt.	,, ,,
	Chambers Street, ,, .	B. Redwood.	,, ,,
	Buchanan Street, Glasgow, . . .	Jarrah.	.. ..
	,, ,, . . .	,,	.. ..
	Charing Cross Post Office, Strand, London,	Creosoted Deal.	Close joints, pitch grout.
14	Kensington, High Street, ,,	Creosoted Deal. American Red Gum. Creosoted Deal.	.. ..
	New King's Road, Fulham, ,,	Creosoted Deal. ,, Dowelled. Creosoted Deal.	Close joints run with pitch and grouted with P.c. grout.
	Lower Regent Street, ,,	American Red Gum.	Close joints grouted with pitch.
100	Whitehall, ,,	,,	.. ..
	Great George Street, ,,	,,	Close joints, grouted with pitch.
	,, ,, ,,	,,	,, ,,
	Eaton Square, ,,	Sanitary Blocks.	.. ..
	Sett-paved Streets—		
	Grove Street, Glasgow, ...	Sq. Whin.	.. ..
	Cedar ,, ,, ...	,,	.. ..
84	Wilson ,, ,, ...	Granite.	.. ..
	Macadamized Roads—		
50	Strathmiglo, Fifeshire, . . .	Macadam.	.. ..
	,, ,, . . .	,,	.. ..
	Pitlessie Road, Cupar, ,, . . .	,,	.. ..
	,, ,, ,, . . .	,,	.. ..
31	Freuchie, ,, . . .	,,	.. ..
40	,, ,, . . .	,,	.. ..
	Prestwick Road, Ayr, ...	,,	.. ..
	Broomfield Road, ,, ...	,,	.. ..
	Main Road near Post Office, Prestwick, .	,,	.. ..
	Bath Street, Glasgow, ...	,,	.. ..
	Kilgraston Road, Edinburgh, . . .	,,	.. ..
	Whitehouse Loan, ,, . . .	,,	.. ..
A.	Lisburn Road, Belfast, ...	,,	.. ..
130	,, ,, ...	,,	.. ..
115	Mount View, Carrickfergus, . . .	,,	.. ..
19	Victoria Embankment, London, . .	,,	.. ..
133	Kinross Road, near Cupar, Fifeshire, .	,, tarred.	.. ..

LXIV.

Tests.

Date when Laid, etc.	Nature of Traffic.	Width of Carriage-way in Feet.	Index of Unevenness in Feet per Mile.		Remarks.
			Slider.	Wheel.	
Aug. 1900.	Medium.	..	6·7	..	Best surface recorded up to the present time.
1899.	,,	..	11·3	..	.. ..
Oct. 1902.	,,	..	13·3	..	. ..
1902.	,,	..	18·0	..	.. ..
1899.	Heavy and continuous.	..	23·4	..	.. ..
..	Very light.	..	7·9	..	.. ..
1896.	Heavy and continuous.	..	17·0	..	.. ..
1875.	Comparatively light.	..	34·2	..	.. ..
Apr. 1899.	Medium.	..	7·8	..	.. ..
Recently.	Comparatively light.	..	10·9	..	.. .
Oct. 1902.	,,	..	15·7	..	.. ..
Aug. 1898.	Medium.	30	7·2	12·7	.. ..
Apr. 1900.	Medium to heavy.	45	9·0	9·0	This is a unique result.
July 1902.	Medium.	..	11·6	13·8	.. ..
Oct. 1900.	,,	..	15·8	17·3	.. ..
Apr. 1900.	,,	..	19·5	20·9	.. ..
Oct. 1893.	Comparatively light.	..	20·0	35·7	.. ..
Mar. 1902.	Heavy and continuous.	..	19·0	25·3	.. ..
May 1899.	,,	..	31·1	44·6	.. ..
Jan. 1902.	Very heavy and continuous. 'Bus and general.	..	20·3	29·2	.. ..
Sept. 1899.	'Bus and general, heavy.	..	31·9 75·7 35·2	44·2 93·2 50·8	Repaved.
Mar. 1894.	,,	..	32·9 24·1 33·7	41·1 29·3 38·4	.. ..
Nov. 1900.	Heavy 'bus and cab.	..	42·7	74·0	Repaved.
Sept. 1901.	Heavy 'bus and general.	..	52·5	63·3	Tested March 1904; repaved 1906.
,,	Light.	..	19·8	24·8	Tested again 2 years later.
,,	,,	..	29·8	67·4	
..	Medium.	..	20·7	31·5	.. ..
1888.	Light.	..	36·0	43·6	.. ..
1902.	,,	..	53·7	98·0	.. ..
Previous to 1888.	Heavy.	..	104·1	216·1	Repaved with asphalt.
3 months after being repaired.	Light.	16	18·58	30·1	Tested November 1902.
..	,,	,,	32·6	53·1	,, December 1906.
1 year after repairs.	,,	,,	23·7	35·4	,, August 1902.
..	,,	,,	30·0	43·0	,, December 1906.
Previous to repairs.	Heavy.	18 to 21.	51·4	83·8	.. ..
After repairs.	,,	..	20·8	46·8	.. ..
1 month after repairs.	Medium.	..	24·1	52·4	.. ..
2 years after repairs.	,,	..	31·5	51·9	.. ..
..	..	..	52·3	116·0	Tested February 1905.
..	..	..	35·4	64·2	.. ..
..	..	..	35·5	98·7	.. ..
..	..	..	57·4	75·1	Tramway crossing paved with setts.
Previous to reconstruction.	Medium to heavy.	..	..	..	Viagraphed by Mr J. Brown, F.R.S.
After reconstruction.	,,	..	27·8	90·5	Tested June 1906.
..	Light.	..	48·2	168·8	,, ,,
2 weeks after repairs.	General, medium to heavy.	..	49·6	151·0	Paved crossing intervening.
1 year after repairs.	Light.	18	12·0	12·7	Tested October 1906

what the condition of a thoroughfare may fall into, resulting in a great loss of tractive power in hauling loads when subjected to such disturbances, while these great depressions also lead to conditions of an insanitary character. The sett paving of this street has recently been lifted and laid with asphalt.

483. Macadamized Roads.—Very variable results have been obtained on macadamized roads. This is accounted for in a measure by the method in which repairs are executed, gauge of road stones employed, quantity and description of binding used, and whether the repairs have been recently carried out or the length of time the roads have been subjected to heavy wheel traffic.

Roads of this class should be tested under normal conditions of weather for comparison with carriageways formed of other descriptions of materials. After long-continued rains or during a thaw after a spell of frosty weather, especially if the road crust has been previously in a wet condition, the results are abnormal and not reliable for fair comparison. The results of tests under these conditions, however, compared with those existing when in a sound state of repair, disclose an enormously greater tractive effort necessary to haul loads over nominally the same roads.

The unevenness of the surface of macadamized roads may vary from 20 feet per mile for slider, which may be considered an excellent result, to 150 feet, or even more, a numerical figure for wheel index by no means uncommon. The ratio between the slider and wheel indices are more variable on macadamized roads than on streets paved with asphalt, wood, or other similar materials. This, in many instances, indicates that metal of too large a gauge or of irregular sizes has been used, or binding in excessive quantities has been applied. When metalling of a regular and uniform size, and of a gauge capable of passing through a 2¼-inch ring, and consolidated by rolling with an amount of binding just sufficient to preserve cohesion is adopted, then the ratio of the slider and wheel indices agree within reasonable limits. On the other hand, large or irregular-sized stones and large quantities of binding give a very variable contour, amounting in some instances in the ratio for slider and wheel index of 1 to 5. In the latter case there will, in all probability, be a great accumulation of mud on the surface in wet weather and large quantities of dust in fine weather.

Some good examples of macadamized roads have been recorded in various centres, and a few of these tests will now be given.

In Stirling Road, Trinity, Leith, the average unevenness of a number of tests was 20·5 feet for slider and 33·4 feet for wheel. In Prestwick Road, Ayr, repaired two months previous to testing, the slider index showed 24 feet and the wheel 52·4 feet of unevenness per mile; while in Bloomfield Road, after two years' wear, the irregularity was for slider 31·5 and for wheel 51·9 feet per mile. In Bath Street, Glasgow, the irregularity was found to be 35·4 and 64·2 feet respectively, and in St. George's Road the unevenness for slider index amounted to 48·8 feet and for wheel 90·1 feet per mile six months after being repaired. In Edinburgh, some profiles were taken in Kilgraston Road and Whitehouse Loan; the irregularity of surface for these roads varied from 35 to 57 feet for slider per mile. These roads had been repaired one or two months previous to being tested.

In Fifeshire, near Strathmiglo,* two half-mile sections of road were tested three months after being repaired, by continuous full-width coatings and consolidated by rolling; the average numerical index of unevenness for slider amounted to 18·5 feet and for wheel 30·1. Viagram No. 50 shows a portion of this road. Profiles of a similar nature were taken on the Edinburgh road, near Cupar, eighteen months after being repaired, as described in the previous test, and the average record of unevenness amounted to 23·7 feet for slider and 35·4 feet for wheel per mile. The records of these two roads have been taken regularly; the latest particulars, including the indices of unevenness, recorded recently, are given in the Table of Tests, pp. 442, 443. Viagrams Nos. 31 and 40 show the profiles of a road at Freuchie, previous to and after being repaired respectively; the records of unevenness and other particulars are given in the Table. In testing a macadamized road, on Kinross road near Cupar, repaired by the process described in Chapter VIII., p. 310, and which may be referred to here as tarred macadam, the record of unevenness after one year's wear amounted to 12·0 feet for slider and 12·7 feet for wheel per mile. The profile of this road surface is shown in Viagram No. 133.

The author has also taken viagraph profiles of macadamized roads in the north of Ireland, a few particulars of which may be given for comparison.

Generally the condition of the roads in counties Down and Antrim are not all that can be desired, and with an ample supply of suitable material for repairs it is strange how the need of good roads has not been recognized long ago. Probably the system of executing the repairs is at fault, and it may be that the want of money has a great deal to do with the condition of the highways. Steam rollers have now been introduced, and the proper use of these, together with such other modern appliances and systems as may be introduced for economically supplying road material in large quantities, will tend to bring about an improvement in the quality of the roads in the immediate future.

The best result obtained around Belfast was on the Lisburn road, where the index of unevenness for slider gave 27·8 feet and for wheel 90·5 feet per mile. This portion of road was reconstructed some time ago, and ought to have shown a better wheel record, but the probability is that too much binding material was used in consolidating the road metal. Viagram A * gives a profile of a portion of this road previous to reconstruction, while Viagram No. 130 shows its condition some time after being repaired.

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* These roads are under the author's charge.

Most of the other roads tested vary in extent of unevenness between that of No. 130 to the condition of the road shown in Viagram No. 115 at Mountview, on the Belfast and Carrickfergus road. The index of unevenness for slider gave 48·2 feet and the irregularity for wheel index was 168·8 feet per mile.

To illustrate more particularly the baneful effects of using too much binding in consolidating macadamized roads, Viagram No. 19 may be cited. The portion of road tested was on the Victoria Embankment, London, from Charing Cross Railway Bridge, eastwards, three weeks after the roadway had been metalled and rolled. The slider index of unevenness in this case was 49·6 feet and that of the wheel index 151·0 feet per mile. The system of repairing this roadway has now been modified, in so far that only about one-half of the former quantity of binding is applied, with correspondingly good results. Viagraph tests would undoubtedly now give better results, a natural expectation under the altered circumstances. This profile also shows the effect of a paved crossing on a macadamized road.

484. These autographic records show that asphalt pavements provide excellent results in the matter of evenness of surface. The hard wood pavements, especially Jarrah and Karri, are nearly equal to asphalt, and are immeasurably superior to creosoted deal. The Australian hard woods and also creosoted deal are equally superior to American Red Gum.

The tests on the latter pavements show that, even after being newly laid, the comparison is not favourable to the Red Gum, and the rapidity of wear, or rather the irregularities of the surface, become very marked after being quite a short period in actual use. This is instanced by tests in Great George Street, London, which were taken at exactly the same spot at an interval of two years. It is also fully exemplified by Viagram No. 100, which was taken three years after the Red Gum was laid. This wood pavement has now been lifted (September 1906) and the carriageway laid with creosoted deal. The former had only been down five years, rather a short life for a wood pavement represented as a hard wood.

As has been mentioned, sett-paved streets do not give good viagraph results. A regular and fine surface are not claimed for this description of pavement, superior wear and good foothold for horses being, under certain weather and traffic conditions, probably of more value than actual smoothness of surface in certain localities.

On macadamized roads the results of the tests made by the viagraph vary very much. The length of time under traffic and the unequal wear and rounding of the stones, and also the proportion of soft to hard material in the crust of a road, influence the regularity of the surface and give remarkable differences, as shown by the numerical index in the Table of Tests. Viagrams Nos. 40 and 50 give a fair average of a good road in regard to these differences compared with the road shown in Viagram No. 19, or that at Carrickfergus, No. 115.

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* Viagraphed by Mr. J. Brown, F.R.S., Belfast, the inventor.

These latter give a clear indication of an abnormal amount of binding or soft material in the road which is likely to produce large quantities of dust in fine weather and mud in wet weather. Roads but recently repaired, the road-stones of which are of a large-sized gauge, and which, of course, require a comparatively large amount of binding for the purpose of consolidating the coating, also give a high index of irregularity, as indicated in the test on Kilgraston Road, Edinburgh. The Lisburn Road, Viagram No. 130, shows a good surface for the slider index but an exceptionally high result for the wheel, which is no doubt caused by the abnormal amount of binding used when the road was repaired.

485. In considering these various viagraph tests, it would appear necessary, owing to the great divergence from a perfectly plane surface, to adopt a standard of excellence for paved streets and also for macadamized roads. A long and varied experience in using the viagraph has led the author to fix for asphalt, wood, and other such pavements a numerical slider index of unevenness up to 20 feet per mile as a standard of excellence, and for macadamized roads, under normal conditions of weather, up to 35 feet per mile.*

The limit to which the irregularity of surface of a road or street should be permitted to go previous to being repaired is more difficult to determine. Various considerations enter into the question, such as whether the roads are of an important nature, the description of traffic accommodated, and other circumstances. What may be considered a fairly good surface in one particular locality may be looked upon in others as in bad condition, so that if anything like uniformity of practice is to be of service to the general public, a certain limit should be placed on the amount of unevenness of the surfaces of thoroughfares when it is imperative that repairs should be made.

Asphalt pavements seldom fall into a very bad condition, as repairs can be readily executed on this kind of surface. It is different with wood pavements, as generally the whole of the blocks have to be lifted and repaired with new material. It often happens that this description of pavement remains longer in use, with an extremely rough and irregular surface, than the requirements of the general traffic demand. The excessive unevenness and wide joints of sett pavements almost preclude classification.

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* The numerical index of unevenness given in the first edition of this work was obtained by the old viagraph with frictional drive, which is superseded in the new instrument by ratchet wheels and pawls. The index of unevenness is greater in the present viagraph, but correct ratios cannot be given.

Macadamized roads also vary much in unevenness, according to the climatic conditions experienced throughout the year, which are more erratic in some parts of the British Isles than in others.

In all probability the limit of unevenness in paved streets might be fixed at 30 to 35 feet for slider per mile, while the ratio of the wheel index does not exceed 5 to 2 of the standard of excellence. When the slider index of irregularity on macadamized roads exceeds 50 feet of unevenness per mile, and a ratio between the wheel index approaches 5 to 2 of the standard of excellence, then the necessity of carrying out repairs should be considered.

These scales of smoothness and of irregularity may appear in some instances too exacting, but when the cost of traction is considered in connection with the unevenness of streets and roads generally, it would appear that still further demands may be made in this direction.

Uniformity and smoothness of surface are essential if a noiseless and durable pavement is required.

486. The irregularity of surface, to any great extent, causes vibration and unnecessary friction, adds to the discomfort of travelling, creates extra wear and tear on vehicles, and entails additional work on the prime mover, and is a direct means of still further damaging the road surface by the concussion of the wheels of vehicles.

On referring to Viagram No. 85, the index of irregularity for slider, namely, 6·7 feet per mile, represents a gradient, assuming the thoroughfare to be level horizontally, of 1 in 758, which inclination may be considered a negligible factor in hauling loads. Taking the case of test No. 85, however, it will be found that the index of unevenness represents in effect, on a practically level road, an artificial hill interposed by the bad state of the surface, representing a gradient of 1 in 50 made up of irregularities alone. Assume that such an irregular surface was situated on a rising gradient of 1 in 50, then the unevenness of the surface would practically convert that gradient into 1 in 25.

Apart from the jolting and lateral swinging action of vehicles against horses on such a rough surface, an additional effort has to be put forward by the prime mover in overcoming not only the natural but also the additional imposed artificial gradient.

The shocks and strains experienced by steam wagons, motor cars, and, indeed, all kinds of vehicles on irregularly paved streets, or on rough macadamized roads, are very great, and the earning value of these vehicles are considerably decreased compared with those travelling over roads offering a fairly regular surface.

487. In connection with the experimental investigations of a committee of the British Association appointed some years ago in regard to "The Resistance of Road Vehicles to Traction," the viagraph, in addition to the special instruments necessary for these investigations, is made use of for recording the exact nature of the road surface. This supplies a definition of the condition of the experiment (hitherto impossible), and provides what was a latent defect in the researches of early experiments on this interesting subject.

CHAPTER XVIII.

SUBWAYS.

488. The importance of the construction of subways or conduits under the street level of our large towns, for the reception of gas and water mains, electric wires and other conductors, so as to obviate the almost daily breaking up of the street pavements in order to lay new pipes, discover and repair leakages, or for other purposes, is a subject of considerable public interest; in fact, the necessity of constructing subways is becoming a most pressing question at the present time.

There is also the possibility of subsidences through leaking or bursting of water mains, and explosions through the same cause in gas pipes, to be considered, besides the monetary loss, which cannot be easily determined.

This subject has received a large amount of attention from time to time, and since the first edition of this work, a move has been made in the direction indicated. During the last few years the construction of high-level viaducts and tunnels or subways has been proposed, in addition to forming new as well as widening existing thoroughfares at important points, as a solution of the congestion of street traffic in London.

The ever-increasing pedestrian traffic has likewise received attention; foot bridges over the carriageways, and subways with a flight of steps leading to the pavements at important street crossings, have been proposed, the latter being the method adopted in connection with the Central London Railway Scheme in the open space in front of the Mansion House, which point has been aptly described as the 'heart of the city.'

The necessity for subways is evident when it is considered that any examination or periodical inspection of the existing mains to ascertain their condition is otherwise impossible, especially where many are placed under the roadways, and it is only when undetected leakages, which may have existed for a long period, become apparent that measures are taken to discover and remedy the evil. Under the circumstances, the only recourse is to break up the street pavement, an operation which may, in many instances, extend over a considerable area of the thoroughfare, and involve a large expenditure as well as great inconvenience.

In large cities and towns the annual cost incurred in tracing and making good the leakage of water and gas mains and connections, and the loss thereby entailed by different public companies, must be considerable, while the deterioration of the pipes which must necessarily take place when situated in subsoils of a variable nature is also a serious matter. The expenditure thus incurred must be enormous when taken collectively, and must not be overlooked; although when divided among several companies it may not appear such a formidable figure.

It is stated that in London many of these leakages cost from 20s. to £20 to discover, exclusive of the actual repairs to the water or gas mains or other connections placed under the ground. The estimate of the City Engineer, Westminster, in connection with trenching operations and reinstating the paving shows that this work costs the companies concerned between £20,000 and £30,000 each year in that city.

The number of openings for access to pipes, etc., in London must be considerable. The recorded openings of streets by public companies and others for 1905, in six of the Metropolitan boroughs, numbered 23,324, and, by a simple calculation, assuming the average in the others to be the same, this represents over 112,000 openings of streets in the Metropolitan area each year. From this statement it appears that these figures, taken in conjunction with the congested traffic in the Strand, which circumstances apply to many leading thoroughfares in other districts of the Metropolis, not only present the most difficult problem to deal with, but also indicate the extent of the advantages which would be conferred by introducing facilities for obviating this constant breaking up of the streets.

The reinstated paving over trenches invariably subsides to a certain extent, necessitating repairs at varying periods to restore the portion of road affected to its proper level, and, apart from the cost of doing this, amounting to thousands of pounds annually, the surface through these irregularities adds to the general unevenness and shortens the life of the pavement. This irregular surface also adds to the effort necessary to be exerted by horses in hauling loads, and the element of danger is ever present. In most instances the carriageway pavement is irretrievably damaged when disturbed for this purpose, its life being materially shortened, besides leading to possible accidents and causing the greatest inconvenience to the traffic and serious loss of trade to business people.

In addition to the large annual expenditure connected with the examination for leakages and the subsequent reinstatement of the pavement, the effect of the percolation of water and the escape of gas permeating the subsoil must necessarily create very insanitary conditions.

489. Early Subways.—One of the earliest attempts to avoid the disturbance of street pavements in connection with laying or repairing pipes under ground, so far as the author is aware; was carried out in Liverpool, and is described by Prof. Rankine.* "One method of obviating this is to provide 'side-trenches,' to contain those underground works, being narrow excavations lined at the sides with brick walls, and situated under the outer edge of the foot pavement, by the flags of which they are covered. The wall of the side trench next the roadway is strengthened against the pressure of the earth by means of transverse walls, with openings in them for tho passage of sewers and pipes; and between these transverse walls the longitudinal wall is slightly arched horizontally. The other longitudinal wall of the side trench forms the back of a row of cellars under the foot-pavement. The side walls of the cellars are in a line with the transverse walls of the side trench, and act as buttresses to give it stability. In the example given in Mr. Newlands' report for 1848 the side trench is 13 feet deep from surface of footway to foundation, 2½ feet wide inside, and has cross walls at every 7 feet; the brickwork is one brick, or 9 inches thick. It contains an oval sewer-pipe 27 inches × 18 inches, a 10-inch water-pipe and a 10-inch gas-pipe. Sewers which are large enough to be traversed by men may be repaired by getting access to them through subterranean passages leading into them from trap-doors in the foot-pavement."

The 'side trenches' constructed in Liverpool to accommodate a sewer and water and gas mains appear to have been made for the sole purpose of placing the pipes in them, without any consideration as to the future requirements of renewal or repair.

The earliest subways of any consequence constructed in this country were carried out in 1862 in Southwark Road and Garrick Street, London, and in Victoria Street, Nottingham, in the year 1863. For many years past subways have been constructed in connection with most of the Metropolitan improvements, such as the Holborn Viaduct, Thames Embankment, Charing Cross Road, Queen Victoria Street, while many have been constructed in existing thoroughfares.

490. One of the most recent subways constructed in London, and known as the Kingsway Subway,† has been carried out in connection with the Strand and Holborn improvements, and was opened for traffic in October 1905.

It is of the triple description, and the centre tunnel, accommodating two lines of trams, is 20 feet wide, with a headway of 14 feet; the side or pipe subways, one on either side of the central one, are 12 feet by 7½ feet, with sewers underneath. The depth of the tramway subway beneath the surface varies from 6 to 14 feet, and the new thoroughfare, for the most part, is 100 feet wide, the carriageway being 60 feet, with footways on either side.

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* *Civil Engineering*, by Prof. Rankine, pp. 629 and 630, taken from Reports by the Borough Engineer of Liverpool (Mr James Newlands).

† *The Surveyor*, 26th February 1904 and 20th October 1905.

The material used in construction is mainly concrete and brick work, the latter in the pipe-subways being protected from decay through damp by a lining of asphalt ¾ inch or more thick. The concrete of the tunnel or tram subway is lined with tiles or enamelled bricks, and illuminated throughout by electric light. The difficulties met with in forming the subways were considerable, owing to the number of water, gas, and other mains encountered, which, as in all such undertakings, necessitated much ingenuity to overcome them.

A subway of novel construction was completed several years ago at St. Helens.* The opportunity of advocating and carrying it out was afforded in connection with the purchase of the tramway system, which it was decided to convert and equip for electrical traction. This decision was further strengthened by the necessity of disturbing the surface of the streets in connection with carrying out these works and for the purpose of renewing the gas and water mains and services, and also for the laying of electrical cables. All these circumstances, combined with the narrowness of the streets, made the proposal to form a subway a decided improvement, whereby the whole of the mains and works beneath the thoroughfares could be properly inspected, while the interference of the paved surface and foundations of the streets would be practically eliminated. The latter circumstance alone, brought about by the almost incessant renewing of gas, water, and other mains, would have been in itself an incentive to construct a subway.

This subway, which measures 6 feet 6 inches by 5 feet 6 inches, is, with the exception of a 4½-inch ring of blue brick to form the arch, entirely built of concrete. The side walls and haunches are extended upwards so as to form the foundation of the paving material of the street, and is about 12 inches above the brick arch; the inclination of the subway follows the gradient of the streets.

No doubt the size of this subway has been determined in view of prospective requirements. At present, it accommodates one gas main 18 inches in diameter, and two water mains, 10 inches and 6 inches in diameter respectively. Lateral ways are also provided, opening on the footway, through which gas and water pipes can be conveyed where required.

The services leading from the subway are enclosed in 6-inch earthenware pipes on either side of the roadway. The subway proper is constructed close to the kerb on one side of the street; it is provided with gullies at intervals for draining surface water to the sewer. Special provision is made, in case of a burst in the water mains, by placing a valve at the lowest point of the subway, which is connected direct with the sewer.

The subway is lighted throughout by electricity, which is so arranged as to be used without fear of explosion should a leakage of gas take place, while it is ventilated at intervals of 100 feet.

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* *The Surveyor*, 26th January 1900.

The cost of constructing this subway, although of ordinary dimensions, is stated to have been £7, 2s. 4d. per lineal yard. This expenditure includes the lateral ways and the electric lighting, and is certainly a comparatively small cost for such an undeniable benefit.

A conduit or subway has been recently constructed in Albion Street, Glasgow, for the purpose of accommodating water, gas, hydraulic power and electric supply mains. The dimensions of this conduit are 6½ feet wide and 7 feet in height. It is built of 14-inch brickwork with a semicircular arch on a concrete foundation. The floor of the conduit is also formed of concrete. The cross connections from the subway to the kerbs are enclosed in fireclay pipes of varying sizes. The cost of this conduit, including the cross connections, amounts to approximately £10 per lineal yard.

The earlier subways constructed in London are deficient in many respects, especially in being too small in most cases for the growing requirements of the city, although in one or two instances a very few mains have been laid in some of them. The most serious objection, however, is that, in the majority of cases, they have been constructed in short unconnected sections of varying size, without any general scheme for carrying out extensions embracing a complete system in any particular district or centre.

491. Tram Subways.—The congested state of many of the leading thoroughfares in our large cities and towns, caused by all descriptions of vehicular traffic, and the loss of time thereby entailed, clearly point to the necessity of providing separate accommodation for fast-travelling passenger traffic, entirely independent of all other kinds of traffic. The fast-travelling electric trams could be accommodated in some well-devised shallow subway scheme, connecting the central or business parts of cities with the various railway termini, or, if necessity arose, the outlying or residential districts.

The widening of existing streets to improve the accommodation is an expensive process, while the construction of subways in all the important thoroughfares must be attended with considerable expenditure, which is considered by many to be prohibitive.

Surface tramways, which practically monopolize the best part of a roadway, inconveniences other kinds of traffic. The cost of constructing these would add considerably to the expenditure involved, but this would ultimately be repaid. The saving in time to business people would be enormous, and this, in a measure, is an indication of its value as an unimpeded route in improving the means of communication between distant points. That the construction of pipe and shallow tram subways, and the widening of narrow streets on important routes, would appear, from the existing conditions of traffic, to be only a question of time. The longer these undertakings are delayed the greater will be the expenditure necessary to carry out the needful improvements, by reason of the higher value of property and the yearly increasing number of mains and other service pipes under the roadway to be encountered and dealt with.

What might be reasonably claimed for a more extended introduction of subways, even taking into account the cost of construction, is that all mains, electric cables, etc., could be periodically examined, and the necessary repairs executed at a trifling cost compared with what it must be under existing circumstances. Tracing leakages by opening trenches, making the necessary repairs, and reinstating the roadway involves a cost, in many instances, beyond what might be considered sufficient to pay interest on the capital expenditure of constructing subways.

492. **Ventilation.**—Objections have been raised that the escape of gas from the mains might produce disastrous results, and no doubt this would happen if the pipes were not properly inspected and prompt action taken for repairing them when necessary. Any leakage of a temporary nature tending in that direction would be easily obviated by efficient ventilation, which is of the greatest importance in any conduit or subway.

It is reasonable to suppose that the life of gas, water, and other mains would be considerably increased if placed in a subway, compared with being laid in the ground and near the surface of the roadway, where a sudden change of temperature adversely affects them. It has been proved by observation that the air in subways does not vary more than about 5° Fahr., while the range of the temperature of the outside air amounts in many cases to about 34° Fahr. The range of temperature in existing subways varies from about 40° Fahr. to 45° Fahr. during the winter and summer months respectively.

The regulations issued in 1893 by the London County Council prohibit the use of naked lights or molten lead in the subways under their jurisdiction, while in the city subways no such restrictions are enforced, open gas lights being in use throughout their length. Such restrictions in regard to the use of naked lights and other matters must seriously hamper the extended use of subways in many districts of London, as the public companies having Parliamentary rights to lay their pipes underground might not be induced to make use of the subways under these conditions.

The municipalizing of public companies, which in large cities is a very complex problem, would in all probability obviate many of the difficulties standing in the way of forming subways on a large scale. If such a course were adopted, these would be constructed, and the mains and other pipes laid, and all the works would be maintained under the jurisdiction of, and be the exclusive property of, one company.

493. The situation confronting engineers in the construction of subways is surrounded with troublesome and perplexing difficulties, the number of mains and cables traversing and occupying the under-surface of the streets which would require to be altered being enormous, while a vast expenditure would be requisite for dealing with them.

In many of the main thoroughfares in London this is especially the case. West Strand, in the City of Westminster, which is a narrow street, for instance; there are thirty pipes and tubes of various diameters running in all directions, and many of which are in unknown or uncertain positions, representing water and gas mains, post office and electric cables, hydraulic power mains, drains and sewers. In addition to these, there are about one hundred openings in the footpaths and carriageway for manholes, surface covers, etc., in that portion of the Strand between Duncannon and Agar streets.

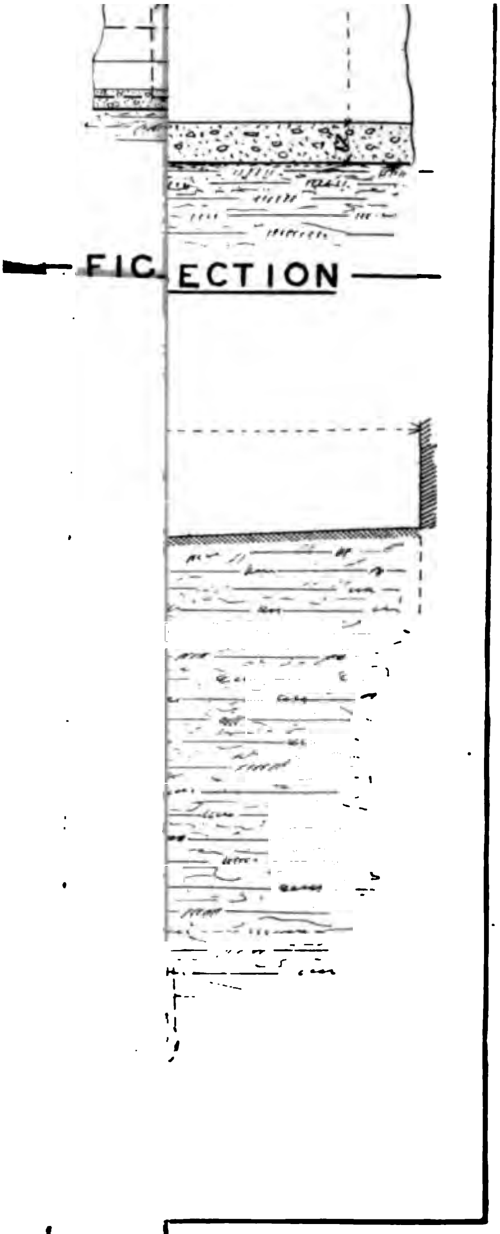
The actual requirements necessary in each thoroughfare must, of course, be determined by circumstances. The number of mains, electric cables, etc., to be accommodated, the width of the streets to be served, and whether shallow passenger tram subways should be constructed in addition, are all factors to be taken into consideration. Instances will, undoubtedly, occur where the introduction of subways would not materially improve existing conditions; as, for instance, in narrow streets with high buildings, where a saturated subsoil of a treacherous nature exists, railway tunnels, high level sewers, and other such conditions might prevail. No doubt a subway could be made under such circumstances, but the cost of construction, so as to safeguard the buildings and render it waterproof, would be out of all proportion to the benefits to be derived therefrom. These cases, however, would, in all probability, be of rare occurrence.

494. Construction of Subways.—No general plan can be definitely recommended as applicable to all conditions. Each individual case must be treated according to the special circumstances which arise, but some uniform system of procedure might be adopted, embodying the best form of construction under the varying combination of circumstances.

Three typical cases will be dealt with, as shown in figs. 1, 3, 3, Plate V.: subways in narrow or moderately wide streets; those in very wide thoroughfares; and those in similar carriageways, but with shallow subways for trams in addition.

In narrow streets, of from 20 to 25 feet in width, a subway placed under the centre of the roadway will adequately serve most purposes. Provision should be made for duplicating water and gas mains, and be of sufficient dimensions for this purpose and also for prospective requirements. The latter condition may be difficult to gauge, but unless this is provided for in the first instance, overcrowding may be the result, when the evil, for the most part which subways are intended to obviate, would be as bad, if not worse than, the original condition of things.

FIG. ECTION



[*To face p.* 457.

In many instances the width of the pipe subways may vary from about 10 to 15 feet, with a headway of 8 feet. The drawing, fig. 1, Plate V., shows a cross section of a subway 12 feet by 8 feet for a carriageway varying in width from 25 to 30 feet. Provision is made for a duplicated service of water and gas mains, and for prospective additional pipes, and also for hydraulic, telegraph, telephone, pneumatic tubes, and other power and service connections. A 2-foot gauge tram line is provided for the purpose of conveying pipes and material to and from the subways for renewals and repairs.

The mains, service pipes, cables, etc., are carried in a steel framework, as this form of construction affords the maximum amount of space for carrying out repairs and facilitating inspection; an available headway of 7 feet is retained in order to allow the workmen to walk erect and have free movement in handling pipes and tools and other material. House connections can be made at different levels to suit circumstances, enclosed in earthenware pipes of large diameter; drainage facilities are provided by fixing gullies at intervals and the most suitable levels, and connected with the sewers. Ventilators are provided where most suitable, either in the carriageway or footpath, or connected with lamp posts, or by pipes fixed to the outside of buildings. Entrances to the subways should be made from side streets or other convenient points, to admit of free access to workmen and material, and protected by iron gates or doors.

The formation of the pipe subway shown in figs. 1 and 2 is of ferro-concrete, the system being that of the Patent Indented Steel Bar Co., which form of construction may be advantageously employed in such work. Ferro-concrete construction occupies less space and is more economical compared with that of the various forms of ordinary concrete construction. There is, however, one disadvantage in that the roof portion requires at least six weeks or two months to thoroughly set and harden. This period of time may be considered excessive compared with the time occupied in fixing steel trough decking, especially in busy thoroughfares; but, on the other hand, ferro-concrete may be looked upon as practically everlasting.

The form of construction shown at C and D in fig. 3 may be adopted; and while the former presents the maximum of capacity, as in fig. 1, the cost of this, and especially that shown at D, is very much greater than the ferro-concrete form of construction. The brick arch shown at D, fig. 3, reduces the capacity of the subway, and consequently the number of pipes accommodated is limited, otherwise the height or headway will require to be increased, involving greater expenditure.

In figs. 1 and 2, and at A in fig. 3, the general features and dimensions of the concrete and steel bars or rods for ferro-concrete construction are shown, and the general arrangement of mains and service pipes or connections to the adjoining houses.

495. In a thoroughfare from 60 feet to 100 feet in width it is advisable to provide two pipe subways, one at either side close to the footpath, as shown at A and D in fig. 3. This arrangement shortens the length of the house connections, which can be laid in earthenware pipes, and can generally be renewed or repaired without serious interference to the footpaths.

When shallow tram subways are to be constructed the arrangement shown at A and B, fig. 3, or constructed practically alongside of each other, but absolutely independent, may be adopted, which is suitable for streets of from 55 to 65 feet in width. In thoroughfares of greater width it appears to be advisable to construct the pipe and tram subways independently, as shown at B and C, fig. 3.

The pipe subway at A is shown 9 feet wide and with 8 feet of headway to concrete beam, 1 foot being allowed for steel framework for carrying service pipes, or a clear headway of 7 feet. A single set of mains is provided which supply one side of the street only, the other side of the carriageway being similarly provided for, and, if necessary, connections with the mains on either side can be made by fixing pipes by straps between the beams, as shown in the figures.

The tram subway, 20 feet × 10 feet, B and C, fig. 3, is shown in ferro-concrete and ordinary concrete and steel trough decking construction, the principal dimensions and particulars being figured and shown in the illustrations. When the triple arrangement of subways is carried out special methods of construction are necessary at important crossings or street intersections. The pipe subways may be laid out, so as to form a continuous system, in a circular manner, making direct connection with several streets. The tram subways might be brought to the street level at these particular points, and some kind of station accommodation provided, or these may be placed at a sufficient depth so as to be under the pipe subways, with accesses to street level. The headway of the pipe subways might be reduced at these particular points, additional width being provided to accommodate all the main and service pipes and afford sufficient space for the workmen carrying on repairs.

The pipe subways must necessarily be connected by lateral passages and entrances at frequent intervals effected in side streets and in convenient places, so as to afford easy access and be properly protected. The drainage, subsoil and surface should be adequately arranged for, and provision made for draining away quickly water from a burst water-main. This latter contingency could only be of short duration, as the subways, being patrolled by inspectors, and the mains and connections being provided with stop valves, the amount of leakage would not be great.

The whole of the subways should be effectively lighted either by electricity or by gas, or both if necessary.

496. The cost of construction of subways is rather a complex problem, and it is questionable, assuming the same size of subway was constructed in any particular street, if the expenditure incurred, apart from actual construction, would be the same in succeeding small lengths or sections of the work. The number and position of existing mains and other pipes, cables, etc., under the street surface vary widely, and no definite sum can be placed against this item of expenditure, or for altering during the progress of constructing the subways, great as it must necessarily be and involving many difficulties.

The following approximate figures for forming pipe and tram subways are given more for the purpose of comparison between the different methods of construction than to state the total ultimate expenditure which would be incurred in lifting the old mains and other service pipes, cables, etc., and reinstating them in the new subway.

TABLE LXV.

Pipe and Tram Subways. Cost of Construction only.

	Cost per linl. yard. £
Pipe subway 12 feet × 8 feet, as shown in fig. 1, constructed of ferro-concrete. Indented steel-bar system, ...	20
Do. do. in concrete and brick arching, ...	22
Do. 9 feet × 8 feet, as shown at A, in fig. 3, in ferro-concrete, . .	16
Do. do. as shown at D, in fig. 3, concrete walls and brick arch, ...	20
Tram subway 20 feet × 10 feet, as shown at B, in fig. 3, in ferro-concrete, .	34
Do. do. concrete and steel trough decking, . . .	39
Triple system or two-pipe and tram subway, as shown in figure. Ferro-concrete construction, ...	67
Do. concrete and steel trough decking for tram and concrete and brick arch for pipe subways, ...	79

497. It will be observed that narrow-gauge tramways are shown in the figures, which are essential for carrying out repairs or renewals. These should be properly equipped with rolling stock for conveying and handling heavy pipes, either for laying an additional line of mains or for renewing existing ones. Suitable entrances for inspection and for handling materials should be provided in side streets where possible, and also connected to some distributing centre, railway depôt, or a wharf, so as to obviate extra handling of pipes and cables, etc. Cranes and hoists of sufficient capacity for handling heavy weights would be necessary for lowering and lifting material to or from the trollies on the tramways. These, for the most part, could be operated by manual labour; but in some instances electric or other power would be advantageous, and the subways be illuminated with either gas or by electric light.

Pipe subways and those for passenger trams, and also subways for pedestrian traffic, should, in the author's opinion, be independent and separate from each other. In addition to these requirements it would be necessary, particularly in the case of pipe subways, and to a certain extent in subways for passenger trams, that the entrances should be controlled by the local authorities to prevent the admission of unauthorised workmen in the former case, and undesirable or suspicious persons to the tramway platforms or stopping-places.

The cost of construction, apart from the difficulties and vested interests, has hitherto been the great obstacle to forming subways in London, as well as to their introduction into other cities. Those already constructed in the Metropolis—that is, the single subways—have cost from £25 to £40 per lineal yard.

Against this head—initial expenditure—however, must be set the demands of the increasing volume of passenger and vehicular traffic, which crowds and makes the public streets impassable, and the introduction of which in many of the leading thoroughfares in London, at least, would confer immediate and incalculable advantages and economies.

These subways are built of brick arching, which not only increases the cost of construction, but also causes considerable delay and annoyance during the execution of the work. By adopting side walls which could be built in trenches (which would not interfere with the traffic to any great extent), and employing steel decking properly coated and kept in repair, the work would be more expeditiously, as well as more economically, executed. Sections of a street could be lifted, the girders then placed in position and the pavement relaid, leaving the soil between the walls to be removed to the necessary depth, and the gas and water mains and other connections to be gradually re-arranged in the subway. This method would, to a great extent, remove the apparently insurmountable difficulty which is at present cited as militating against the formation of subways.

498. The number of the companies having mains and other service pipes placed beneath the roadways in London are numerous compared with some years ago, when there were only three of these who had statutory powers enabling them to open streets.

The powers conferred on these private companies practically set aside the authority of the various councils, or at least permit great opposition to be offered to any schemes which might be in the interests of public convenience and protection. The control exercised by the local authorities over those private companies is therefore reduced to a minimum, which is also likely to create a considerable amount of friction. Apart from this inconvenience to the public, and the loss of business to frontagers in the street, the ratepayers have to pay for large sums expended for re-paving and repairs, owing to the shortened life of the pavements caused by repeated openings.

These private companies have a vested interest in the streets, and the powers necessary for the construction of subways by local authorities will have to be authorised by Parliament, who have freely granted rights to private companies in the past.

Owners of property affected by the formation of subways, as in the case of vaults and cellars, are the private companies involved who would necessarily have to be compensated, while, in return, the latter might be reasonably expected to pay handsomely for occupancy under the improved conditions and the lessened cost of maintenance charges under the new system.

If subways are extensively constructed, there can be no doubt that the subsequent convenience and gain to the various communities, to business, as well as to the water, gas, and other companies interested, and to the local authorities, would be sufficiently great to justify the preliminary sacrifice that would necessarily be involved. It is in London where not only the construction of subways presents the greatest problem, but where it would confer the greatest boon by avoiding the breaking up of the streets, which, in most of the leading thoroughfares, is practically of daily occurrence.

499. Passenger Subways.—With reference to subways for pedestrian traffic, the best example of this kind hitherto executed is in connection with the Central London Railway at the Bank Station, Mansion House.

This public subway, which was constructed by the Railway Company, is situated immediately under the street pavement, and is of an oval shape in plan. There are six entrances to the subway for ordinary foot traffic, not only to the Bank Station, but for the purpose of proceeding from one street to another at this extremely busy and crowded spot.

The several entrances are situated at the following different points:—(1) On the pavement in front of the Royal Exchange, and following a north and west direction; (2) on the pavement in front of the Union Bank; (3) on the pavement at the junctions of Queen Victoria Street, Poultry, and Walbrook. On the south and eastwards (4) at Mansion House Place; (5) at the north-east corner of the Mansion House; and (6) on the pavement in front of the Liverpool and Globe Insurance Company's office. The subway then joins the starting-point under the pavement in front of the Royal Exchange.

This subway for foot traffic is 15 feet wide, lined with glazed tiles and covered with steel decking and concrete, and the whole length is illuminated with electric light.

As the subways are placed immediately below the surface of the street pavements, the flights of steps leading to the footways are of easy access, an arrangement which is of immense benefit to pedestrians.

Another subway, placed directly under that just described and of a similar width, has been constructed for the purpose of accommodating gas and water mains, electric light wires, and sewers.

APPENDIX TO CHAPTER I.*

ON THE RESISTANCE OF ROAD VEHICLES TO TRACTION.

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I. *Preface.*

The first ten sections of this Report give a summary of the work done on road resistance from the earliest time for which records are available. It is quite possible that the work of some investigators may have been overlooked, but at the same time the chief results which have hitherto been made known are presented, for the first time, in a concise form. The work of most of the French observers has been drawn to a great extent from A. Debauve's *Manuel de l'ingénieur des ponts et chaussées.*

It has not been possible to carry out during the present year in a sufficiently complete manner the experiments with the British Association apparatus in order to be able to compare the results obtained with the formulæ and laws which the summary gives, but it is hoped that by another year the work will have been sufficiently advanced to enable this to be done.

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* Report of the Committee, consisting of Sir Alexander Binnie (Chairman), Professor H. S. Hele-Shaw (Secretary), Mr. T. Aitken, Mr. T. C. Aveling (Treasurer), Professor T. Hudson Beare, Mr. W. Worby Beaumont, Mr. J. Brown, Colonel R. E. Crompton, C.B., Mr. A. Mallock, Sir D. Salomons, Bart., Mr. A. R. Sennett, Mr. E Shrapnell Smith, Sir J. I. Thornycroft, and Mr. W. H. Wheeler. (Drawn up, at the request of the Committee, by the Secretary, assisted by Mr. J. F. Gill, B.Sc.)

II. *Corréze and Manès* (1832).

MM. Corréze and Manès treated the subject from both theoretical and practical standpoints, and the conclusions they arrived at fully confirmed a series of experiments made by a commission of engineers in 1816.

The following are their conclusions:—

That the resistance to rolling is composed of two elements: (i.) Friction of the wheel upon the road; (ii.) axle friction.

(i.) That wheels of vehicles destroy the road in proportion to their load, width of tyres, and speed. If the tyres be narrow the friction may be simply treated as a rolling friction, but if the tyre be wide then a pivoting action is introduced.

The effect which a wheel produces upon the road depends upon the load upon the wheel, the resistance of the material of which the road is made, and on the nature of the surface. If the load be great and the tyres narrow, the wheel will form a rut in the road, but if the tyre be wide, the load becomes distributed and does not damage the roadway. A wheel travelling along a road badly kept or badly constructed meets with obstacles against which it strikes and surmounts with difficulty, and from which it falls to the ground again with a force proportional to its weight and the height of the obstacle. This action, being continually carried on, is very destructive to the roads.

In cases where roads are uneven, springs should carry the load, as they convert the series of shocks into a simple increase of pressure and preserve the horizontal component of the force, which otherwise would be lost.

The destructive effect of a wheel upon the road increases with the load, the speed remaining constant, but the rate of increase of damage to the road is far greater than the increase of the load.

The influence of speed is such that, with equal loads on a well-kept road, the destructive effect of the wheel decreases with an increase of speed, but on a badly-kept road the reverse takes place.

MM. Corréze and Manès proved, by direct experiment, that the ratio between the tractive effort and the load increases with the speed.

Carriages with four wheels in unequal pairs require less tractive effort than those with two wheels or two equal pairs of wheels.

(ii.) *Axle friction.*—By the contact of a spindle with its bearings a sliding friction is produced.

Suppose the coefficient of friction $= \frac{1}{10}$, and load $= P$,

Then total resistance due to axle friction $= \frac{1}{10} P$;

If ratio of radius of wheel to that of axle $= \frac{1}{20}$,

Then $\frac{\text{resistance at axle of wheel}}{\text{resistance at circumference}} = \frac{1}{20}$.

Therefore resistance at circumference $= \frac{1}{200} P$.

But on a good road resistance to traction $= \frac{1}{25} P$.

So the axle friction only $= \frac{1}{8}$ that of total resistance.

Edgeworth experimented and found, in 1808, that on a rough road a vehicle with springs had only one-third the resistance of one without, at 8·8 kilometres per hour.

III. *The Work of Coriolis* (1835).

Coriolis, a civil engineer, applied the theorem of work to the traction of vehicles and investigated the work of resistance. He proceeded as follows:—

Let F equal the tractive effort and *s* the distance run. Then the integral of the quantity F *ds* will equal the total work due to the reaction of the ground.

The work of resistance consists of:—

(i.) That absorbed by the play of the springs, usually negligible.
(ii.) That due to the action of the wheels upon the road.
(iii.) Axle friction.
(iv.) That absorbed by hills.
(v.) That due to the variation of the momentum, which may be neglected during a day's run, as the vehicle passes in a short time from a state of rest to its normal velocity.

Coriolis states that the tractive effort required is practically proportional to the work due to the action of the wheels upon the road and axle friction, the other quantities being negligible.

That axle friction is a sliding friction constant in value and independent of the extent of surface in contact, and can be reduced by altering the arc of contact, which is limited by practical considerations.

That the reaction of the road upon the wheel would be nil if the ground were infinitely soft, and equal to the load if incompressible. Neither case appears in practice, but the reaction is variable and increases with the compression.

If p = reaction of the ground, h = compression of the road, then work of resistance $= \int p dh = \int \frac{p dh}{dp} . dp.$

The more rigid the ground the more will p increase with h; $\therefore \frac{dh}{dp}$ will diminish with p, and the work will be less for a given value of p.

That the reaction depends not only on the nature of the road but also on the diameter of the wheels and width of the tyres.

That on a homogeneous surface the resistance due to reaction

$$= \frac{a^3 \sqrt{p^4}}{\sqrt{L^3} \sqrt{R^2}}.*$$

a = coefficient that varies inversely as the hardness of the road; p = total load; L = width of tyre; R = radius of the wheel.

Coriolis drew the following conclusions:—

That to reduce the work due to resistance the road ought to have as great a rigidity as possible, and that the springs should be as flexible as possible.

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* This formula is midway between General Morin's and Dupuit's.

IV. *Experiments and Conclusions of General Morin* (1837-42).

These experiments were made by General Morin, 1837-42, by order of the Ministers of War and Public Works, being carried out with the greatest care and under the most varied conditions. The results have been collected together into a large treatise, from which the following is taken:—

A Résumé of General Morin's Work on Rolling Friction.

(*a*) There is the simple turning of one curve upon another when the two curved surfaces are always in contact, and when the arcs passed through in a given time are of equal length.

(*b*) Simple rotation of a cylinder upon a horizontal surface, when the surface formed on the plane is an envelopment of the cylinder.

A cylindrical body alone can roll upon a plane in a straight line. If the body be not cylindrical, the rolling motion is accompanied by a sliding one, or, what amounts to the same thing, a pivoting motion.

This action is particularly noticed when a wheel with a cylindrical tyre leaves one straight line direction for another, and such a wheel, when rounding a curve, is subjected to simple rotation and also a pivoting action about its vertical axis, and consequently tends to twist the wheel from its true position to take up a position relative to the curve.

Morin experimented in the following manner:—Upon two parallel beams, with horizontal faces, were placed two loaded cylinders. In order to give motion to these cylinders additional weights were added, acting tangentially to the cylinders and parallel to the beams.

For different cylinders and surfaces the force required to impart motion was found by experiment.

The force thus found, which imparted a uniform rolling movement to the cylinders, must be that which just overcomes the resistance to rolling, for if the force were too great, the motion would become uniformly accelerated, and if the force were too little, the cylinders would come to rest.

Consequently, from the above, it may be inferred that the moment of the additional weights about the axis of rotation is equal to the moment of the frictional resistance about the same axis.

Calling R the resistance due to friction, which is supposed to act tangentially to the wheel, of which r is the radius, p the pressure transmitted by the wheel to its supports, and A a constant; then we have

$$R = A\frac{p}{r},$$

which sums up the law for rolling friction.

From the experiments, which were made by Morin to ascertain the truth of Coulomb's Law, he drew the following conclusions:—

(i.) On fibrous materials, such as wood; on spongy textures, as leather; on granular bodies, as plaster: "That the resistance to rolling varies inversely as the diameter of the wheel, measuring this force (R) at the circumference of the wheel."

(ii.) On compressible surfaces: "That the resistance to rolling increases as the width of the tyre diminishes."

(iii.) On an elastic substance, such as indiarubber: "That the depth of the depression is practically proportional to the pressure, provided that the elasticity remain constant; the depth of the depressions increases as the width of the tyre diminishes. The elastic reaction, or the force with which the substance tends to return to its original form (after the pressure has been removed) is not always very rapid, even in the case of india-rubber, so it is much less so on a stone road; in consequence, it does not restore to the wheel the whole force expended on it. Even on railways, where the rails return very quickly to their normal shape, the speed of the train is too great for the vehicles to recover the work that has been transmitted to the rails."

(iv.) On a homogeneous body, such as wood: "That the pressure alters the elasticity, and that the resistance to rolling increases more rapidly as the pressure increases; consequently wood pavements are not suitable for heavy traffic."

The law for the ratio of rolling friction to the pressure, enunciated by Coulomb and others, is not a general or mathematical law, but only approximately true for certain cases in which it is found useful to apply it.

Coulomb's Law.

$$R = A\frac{p}{r}.$$

Values for A, the constant, are as follows:—

1. For oak wheels running on poplar boards, the grain of the oak being perpendicular and that of the poplar parallel to the line of motion, ...	=0·000876
2. For oak wheels on strips of leather, ...	A=0·001895
3. For oak wheels on plaster, ...	A=0·000821

Experiments on the Haulage of Vehicles.

For the following experiments, General Morin made use of three kinds of apparatus:—

I. A shaft, to which a number of equal pulleys were attached, so that the width of surface in contact could be varied; a number of metal discs were attached to the axle to act as a load.

The force required to produce uniform rotation was found by trial on well-beaten clay, fine sand, slabs of marble, boards, etc. In each case the resistance (R) was calculated, being equal to the motive weight multiplied by the inverse ratio of the diameter of the axle to the diameter of the pulleys. Thus it was found that the resistance varies with the load and other circumstances met with in the experiments.

II. A shaft carrying a number of discs to vary the weight, and having two wheels formed by a number of pulleys. In this manner the diameter of the wheel and the width of the tyre could be varied at will.

The axle was attached to a metal frame, to which one or more horses were harnessed. A dynamometer recorded the tractive effort by means of a pencil in contact with a roll of paper which was unrolled, the movement of the paper being proportional to that of the wheel, and the deflection of the spring to that of the tractive effort. The area of the figure enclosed measured the work.

III. A dynamometer was interposed between the shaft and the fore-carriage. The tractive force was quite easily transmitted by this method. Most of Morin's experiments were performed in this manner.

The causes that have an effect on the tractive effort and also tend to destroy the roads are—

(i.) The weight or pressure upon the ground.
(ii.) The diameter of the wheels.
(iii.) The width of the tyres.
(iv.) The velocity of the vehicle.
(v.) The angle of inclination of the pull.
(vi.) The efficiency of the springs.

From each experiment Morin obtained a value for F, the tractive effort, or the pull exerted by the horse. This value corresponds to values determined from—

The inclination of the ground	(i)
The inclination of the pull	(a)
The weight of the shaft and its additional load	(P)
The weight of the frame and pole	(p)
The total rise of the ground during the run .	(h)
The distance run	(L)
The coefficient	(f)

Now $\sin(i) = \frac{h}{L}$, and the total pressure transmitted to the ground $= (P + p)$. Applying the theorem of work to the movement of the vehicle:—The force F acts through a distance L, and its direction makes with the surface of the ground an angle (a).

Therefore the work done in moving the distance L is equal to $FL \cos a$.

Work due to resistance is composed of—

(i.) That due to the weight of the vehicle, etc., and which is equal to the weight multiplied by the total rise.

$$\text{Work due to weight} = (P + p)h.$$

(ii.) That due to the reaction of the ground upon the wheel:—Calling R that reaction or resistance to rolling, which acts tangentially to a wheel whose radius is r, and if the tyre develops itself exactly upon the road, the point of application of the force travels a distance L, then

$$\text{Work due to the reaction of ground on wheel } (R) = RL.$$

(iii.) That due to the friction of the axle in its bearings:—The spindle is acted upon by two forces, *i.e.* the pull F, which makes an angle of $(a + i)$ with the horizon, and the weight or vertical force (p). The resultant of these two forces is normal to the circumference of the axle, and is represented by the third side of a triangle of which F and P are the other two, making between them an angle of $\left(\frac{\pi}{2} + a + i\right)$;

$$\therefore \text{Resultant} = \sqrt{F^2 + P^2 - 2Fp \sin(a + i)},$$

and if we multiply this expression by the coefficient of friction (f) we obtain the tangential rolling force applied to the spindle. The distance travelled by its point of application is equal to the distance (L) run by the wheel multiplied by the ratio of the radius of the spindle (ρ) to radius of the wheel (r).

Then the work due to the friction of the axle in its bearings

$$= \mathrm{L}\frac{fp}{r}\sqrt{\mathrm{F}^2 + p^2 - 2\mathrm{F}p \sin(a + i)}.$$

The velocity of the vehicle was kept uniform throughout the experiments, and the variation of the momentum of the system was zero.

The equation of work becomes—

$$\mathrm{FL} \cos a = \pm(\mathrm{P} + p)h + \mathrm{RL} + \frac{fp\mathrm{L}}{r}\sqrt{\mathrm{F}^2 + \mathrm{P}^2 - 2\mathrm{F}p \sin(a + i)}.$$

And $\mathrm{R} = \mathrm{F} \cos a \pm (\mathrm{P} + p)\frac{h}{\mathrm{L}} - \frac{fp}{r}\sqrt{\mathrm{F}^2 + \mathrm{P}^2 - 2\mathrm{F}p \sin(a + i)}.$

The effect of the last term in this equation is very small; it attains its highest value when $(i) = 0$, but usually $\tan a = \cdot262$, $\sin a = 0\cdot255$, $\frac{p}{r} = 0\cdot02$, and $f = 0\cdot065$.

Substituting these values in the equation, it will always be found that the friction of the axle is less than $\frac{1}{50}$th to $\frac{1}{100}$th of the tractive force.

Now, neglecting the last term and making $\cos a = 0\cdot967$, the formula is reduced to the expression—

$$\mathrm{R} = 0\cdot967\ \mathrm{F} \pm (\mathrm{P} + p)\frac{h}{\mathrm{L}}.$$

The values of h, L, P, and p are known, and the dynamometer gives F; the resistance R can then be determined. Representing R by an ordinate to a given scale, rectangular axis ox and oy can be chosen; if from the axis x the values of the element which varies—*i.e.* the weight $(\mathrm{P} + p)$—be marked off, and at the extremity of each of these values an ordinate corresponding to the value of R be raised, then a number of points can be determined lying on a curve, and from the form of the curve can be found the law which governs the ratio between the resistance R and the variable element.

The preceding formulæ only apply to traction upon level roads.

The following are the conclusions drawn from General Morin's first series of experiments:—

I. "The resistance to traction on macadam or paved roads (taken relatively to the axle parallel to the ground) is proportional to the pressure and inversely proportional to the radius of the wheel."

II. "The deterioration of the road due to the vehicle increases as the wheels decrease in diameter."

III. "The resistance is very nearly independent of the width of the tyres on macadam or paved roads for sizes above 0·08 m. to 0·10 m. in width."

IV. "On compressible roads, such as loose earth, sand, gravel, and new macadam, the resistance to traction decreases as the width of the tyre increases; the proportion depends upon the condition of the road. On hard roads it is useless to employ wide tyres, and on macadam in the ordinary state the tyres should not be wider than 0·10 m. to 0·12 m."

V. "On soft ground, such as soil, sand, earth driftways in good condition, rutty roads, or layers of gravel on hard ground, the resistance is independent of the speed of the vehicle with or without springs."

VI. "At a walking pace on all roads the resistance is practically the same for all vehicles."

VII. "On macadam or paved roads the resistance increases with the speed." The rate of increase of resistance is nearly in proportion to the increase in speed, with an initial speed of 1 m. per second. The less rigid the vehicle, the better the springs of the vehicle, and the more uniform the road, the less will be rate of increase of resistance.

VIII. "On good sandstone pavement, well laid and uniform, the resistance at walking-pace is only three-quarters of that on the best macadam; and for vehicles well hung, the resistance at trotting-pace on good pavement is equal to the resistance on good macadam. But on bad pavement, with the setts too far apart, the resistance at trotting-pace is more than that on good macadam, even with vehicles with the best springs."

IX. "The inclination of the line of draught, for the maximum useful pull, increases with the resistance due to the surface of the road and as the diameter of the fore-wheels diminishes. On the ordinary road the inclination tends to the horizontal, so much as the construction of the vehicle will permit."

These preceding facts were not always borne out by the experiments conducted by General Morin, so he was requested by the Minister of Public Works to undertake a further series of experiments in order to set at rest the following questions:—

I. Is the deterioration of the surface of the roads in inverse ratio to the width of the tyres, with equally weighted vehicles?

II. Can vehicles be loaded proportionally to their width of tyres?

III. Is the deterioration of the road in inverse ratio to the diameter of the wheels?

IV. Can vehicles be loaded in proportion to the diameter of the wheels?

V. Which causes more damage to the road, a light dog-cart or a country cart, both equally loaded?

VI. What is the rate of deterioration of roads in different states of repair?

After a further series of experiments he replied as follows:—

(i.) To say that it is legitimate to weight vehicles proportionally to their width of tyres, assumes the hypothesis that the tyre presses equally upon the ground throughout its whole width, which is not a correct basis.

(ii.) Equally weighted wheels with tyres 0·06 m. in width deteriorate the roads more than those with tyres 0·115 m. to 0·165 m. There is no marked difference from 0·115 m. to 0·165 m. in width, so about 0·115 m. is the maximum.

(iii.) A four-wheeled vehicle (wagon) with tyres 0·060 m. in width, diameter of fore-wheels 1·3 m., diameter of rear-wheels 1·5 m., can be loaded up to 2400 kilos in dry weather and 1800 kilos in the rainy season.

(iv.) Vehicles equally loaded, and with the same width of tyre, deteriorate the road more as their diameter is decreased within certain limits. The least diameter of the fore-wheels of a wagon should be 1 m. if it will allow them to turn under the frame. This limit is fixed upon in order not to raise the centre of gravity too high. The diameter of the wheels can be decided upon with due consideration to the centre of gravity and position of axle and frame.

(v.) A load of 2465 kilos drawn by a vehicle with tyres 2·029 m. in diameter and in width 0·115 m., on a good macadam road, does not cause any appreciable damage to the roads, even if the road be wet on the surface. But a load of 5000 kilos drawn on a cart with wheels 1·83 m. in diameter and tyres 0·165 m. wide, or a load of 7935 kilos drawn on a four-wheeled wagon with tyres 0·16 m. wide and fore-wheels 1·011 m. and rear-wheels 1·73 m. in diameter respectively, produces a considerable deterioration upon the road. Therefore the load should not exceed 3500 to 4000 kilos.

TABLE LXVI.

General Morin's Table for the Ratio of Tractive Force and Total Load.

Description and state of roads.	Artillery wagons.	Goods wagons.	Carts.	Coaches and carriages with springs.
Turf, softened by melting snow,	1/8	...	...	...
,, firm, ...	1/20	...	...	...
,, very dry, . . .	1/24	...	...	...
Earthways in good condition, dry, etc., ...	1/30	1/27	1/40	1/26
Earth road, covered with untrodden snow, . . .	1/16	1/15	1/21	1/13
Firm earth, with a bed of sand or gravel ·1 to ·15 m. in thickness,	1/8	1/8	1/12	1/8
Macadam, dry and uniform, .	1/54	1/50 to 1/58	1/66 to 1/82	1/47 walking. 1/40 trotting.
,, wet and dusty, projecting stones, .	1/33	1/35 to 1/41	1/47 to 1/58	1/33 walking. 1/25 trotting.
,, firm, slight wear, and soft mud, . .	1/30	1/27 to 1/31	1/30 to 1/45	1/28 walking. 1/20 trotting.
,, firm, with ruts and very muddy, . .	1/24	1/22 to 1/25	1/29 to 1/36	1/21 walking. 1/17 trotting.
,, worn and covered with thick mud, . .	1/20	1/18 to 1/21	1/25 to 1/31	1/18 walking. 1/15 trotting.
,, badly worn and rutty, mud very thick, .	1/16	1/14 to 1/16	1/19 to 1/25	1/15 walking. 1/11 trotting.
,, very badly worn and with deep ruts, hard foundation and unequal surface, .	1/14	1/12 to 1/15	1/17 to 1/21	1/12 walking. 1/10 trotting.
Sandstone roads, well set and closely laid, ...	1/70	1/64 to 1/75	1/86 to 1/107	1/62 walking. 1/35 full jog.
Roads paved with Fontainebleau sandstone, dry, . . .	1/65	1/59 to 1/69	1/80 to 1/100	1/57 walking. 1/58 trotting.
Paved roads, wet and covered with mud, ...	1/50	1/46 to 1/53	1/61 to 1/76	1/44 walking. 1/33 trotting.
Timber flooring of a bridge, .	1/46	1/42 to 1/49	1/71	1/41 walking. 1/41 trotting.

(vi.) A load of 1800 kilos on a cart with tyres 0·06 m. in width, on a good macadam road with a wet surface, causes considerable deterioration to the roadway; therefore the maximum load under these conditions should not exceed 2000 kilos, unless their tyres exceed 0·07 m. in width.

(vii.) The distribution of a load on two or more vehicles, producing a distribution of the pressure over a larger surface, causes less damage to the road.

(viii.) A load of 8000 kilos on a macadam road with a wet surface causes considerable damage, and this limit ought to be considerably reduced if the roads are to be kept intact.

(ix.) A spring carriage going at a trotting-pace with loads of 5000 kilos on macadam roads with wet surfaces does not cause any more damage than the same vehicle without springs proceeding at a walking-pace.

(x.) The best limit to fix for the fore-wheels of wagons is 1 to 1·10 m., and for the rear-wheels 1·50 to 1·60 m., in accordance with the construction of the vehicle.

The foregoing table (LXVI.) gives the results (after General Morin) of the relation between the tractive effort and the total load for different kinds of roads and vehicles.

Below is General Morin's table for the maximum load that can be drawn on a level road.

TABLE LXVII.

Class of vehicle.	Winter.	Summer.
Country cart, with 1 horse, . . .	1800 kilos.	2000 kilos.
Four-wheel vehicle, with 2 horses, . .	2400 ,,	2800 ,,
,, ,, 4 horses, . .	4800 ,,	5200 ,,
,, ,, 6 horses, . .	7200 ,,	9100 ,,
Cart, with 1 horse, ...	1800 ,,	2500 ,,
,, 2 horses, ...	3500 ,,	4000 ,,
,, 3 horses, ...	4500 ,,	5000 ,,

General Morin's experiments decided for the time being the dimensions of the wheels and the maximum loads that vehicles should be allowed to carry. He strongly recommended the erection of weighing machines on all the principal thoroughfares.

V. *The Researches of M. Dupuit.*

General Morin's experiments were fully accepted by the scientific world; they were, however, fiercely attacked by a civil engineer, M. Dupuit, who, after much experimenting, arrived at formulæ which differed considerably from those of Morin.

M. Dupuit pointed out a number of errors in the calculations given in Morin's tables, and leads us to suppose that these suggest many others in Morin's preliminary calculations, of which the results only are shown in the tables.

He states that the figures obtained differ considerably from those that give the proportion of the load to the diameter of the wheel; that General Morin commits a serious error in his value for axle friction, *i.e.* $f = 0·05$, which is too small, and ought to be 0·12. That the distance travelled per revolution ought to be calculated from the diameter of the interior of the nave, as there is considerable play between the axle and the nave. That for the proportion of the tractive effort to the diameter of the wheel Morin compares experiments taken under various conditions, which removes all certainty from his results. That in Morin's experiments on the width of tyres, the pressure and width of tyre are varied at the same time, so that it is impossible to distinguish the part played by each in the experiments.

After pointing out these errors in General Morin's experiments, Dupuit proceeded to conduct experiments exactly similar, but with his own apparatus, which was attached to a special car and had the advantage that experiments could be performed more quickly, as the vehicles to be tested had only to be attached to the dynamometer coupling on the special car.

Dupuit experimented on the resistance to rolling of cylinders, by placing at the top of an inclined plane wheels which were allowed to roll down and run along the level until they were brought to a state of rest by the frictional resistance.

If h = height of incline; P = weight of wheel; S = distance travelled along incline and level; R = resistance to rolling, then resistance offered to the weight P will be PR. The work due to resistance will be PRS, and the equation of work which equalises the work done by the weights to the work of resistance will be

$$Ph = RPS \qquad \text{or } R = \frac{h}{S}.$$

Taking the square root of the diameter D of the cylinders, and obtaining the product $R\sqrt{D}$, Dupuit found that it always gave a constant number, which proved that the resistance to rolling varies in inverse ratio to the square root of the diameter, and not as the first power, as stated by Morin and Coulomb.

M. Dupuit concludes from his experiments that on uniform surfaces generally, as macadam:

(1) The tractive effort is proportional to the load.
(2) „ „ independent of the width of tyres.
(3) „ „ inversely proportional to the sq. root of the diameter of the wheels.
(4) „ „ independent of the velocity.

That the tractive effort or horizontal force necessary to move a vehicle on the level is expressed by the formula

$$T = \rho\frac{\sqrt{2R}}{P}$$

P = weight of vehicle; ρ = a constant which expresses a ratio between the compressibility and elasticity of the surface.

The constant ρ is found from the formula

$$\rho = \frac{3}{8}\frac{\epsilon}{\sqrt{\epsilon'}}$$

in which ϵ is the instant compression of the ground, and ϵ' the permanent set due to the load.

On paved roads, Dupuit recognised that the formula had to be modified, for although the force required is always proportional to the load and to the square root of the diameter of the wheels, yet it increases with the speed, and diminishes as the width of tyre diminishes within certain limits, and also that springs diminish the force required, whereas on macadam springs have very little influence.

TABLE LXVIII.

Dupuit's Table for the Ratio of Tractive Force to Load.

Class of vehicle.	Diameter of wheels.	Width of tyres in metres.	Ratio of tractive force to pressure on		
			Macadam. Walking or trotting.	Paved roads.	
				Walking.	Trotting.
Cart, . . .	1·82	·05	·032	·012	·028
Rubbish cart, .	1·85	·075	·031	·0205	·028
,, ,, .	1·89	·11	·03	·0176	·028
,, ,, .	1·90	·14	·03	·0166	·028
Gig, . . .	1·48	·05	·036	·024	·034
Carriage, . .	1·96	·17	·029	·0177	·028
Char-à-banc, .	1·50	·05	·036	·03	·037
,, .	0·86	·05	·036	·03	·037
Coach, . .	1·5	·13	·029	·016	·02
,, . .	0·95	·13	·029	·016	·02

Dupuit found that the mean force required to draw a vehicle loaded up to 1000 kilos was

On macadam roads = 30 kilos.
On paved roads = 20 kilos.

That on flagstones perfectly dressed the tractive force required equals 6 kilos per ton, and that on asphalt equals about 10 kilos per ton. From the above he obtained the following ratio:—

The resistance on railroads : the resistance on pavements : the resistance on macadam :: 1 : 4 : 6; but these resistances are not in proportion to the respective roughnesses, which are as 1 : 15 : 36.

M. Dupuit performed experiments on the effect of the width of tyres, and carefully noticed the manner in which they wore. He found that the edges became furrowed into deep grooves, and that some particles of the stretched iron became detached; also that the wood having at first a rectilinear section was found after being considerably used to be elliptical.

Experiments were made with wide tyres, and it was found that for a tyre 17 cm. in width only 9 cm. were in actual contact, and 6 cm. of a 14 cm. tyre; from this he concluded that the length of contact is of more importance than the width, this being at least 14 cm. for a tyre 2 m. in diameter; that wide tyres are only useful when they bear on the road throughout their whole width, and in cases when the road is soft, uneven, and in a bad condition.

Dupuit states that from actual experiments he found that a tyre of 17 cm. after a few weeks' wear was reduced to 14 cm. and after a few months' to 11 cm., and that after a 17 cm. tyre had been run 4000 miles it was worn out and showed a loss of one kilo for every 20 miles and per ton of useful load carried.

And, moreover, since the tyre is rounded, it is necessary to admit that the pressure is unequal throughout its whole width, and that not only does it diminish on both sides of the centre but to the right and left, that the surface in contact is not square or rectilinear in section but elliptical, forming an ellipse, the major axis of which increases far more rapidly with the diameter of the tyre than the minor axis increases with the width of tyre.

From another series of experiments Dupuit proved that under a pressure of 2000 kilos, scarcely $\frac{1}{10}$th of the material of the road was subjected to any strain. From this he concluded that 4000 kilos might be taken as a standard load for a two-wheel vehicle, and the weighting distributed as follows:—

Wheels (one pair), . . .	600 kilos.
Axle and frame, ...	520 ,,
Useful load, ...	2880 ,,
	4000 kilos = total load.

Dupuit on the Effect of Hollows and Rises in Roads.

Dupuit obtained the following formulæ:—

$$\Theta' = \Theta\sqrt{\frac{1}{1-\frac{R}{R}}} \text{ and } \Theta'' = \Theta\sqrt{\frac{1}{1+\frac{R}{R_1}}}$$

in which

Θ = tractive force on the level.
Θ' = ,, ,, in a hollow.
Θ'' = ,, ,, on a rise.

R = radius of the wheel.
R_1 = radius on surface of the road, either concave or convex.

By giving different values to R_1 in reference to R, Dupuit found that the hollows have the effect of increasing the pull to a large extent, and their influence has a greater effect as the diameter of the wheel increases, and that the rises had the effect of decreasing the pull; but that the increase was always greater than the decrease.

From experiments Dupuit concluded that, providing the road was undulating and had no very sudden rises or depressions, the effect of the undulations was practically nil.

VI. *Theoretical Investigations of Edmund Leahy, C.E.* (1847).

In an exhaustive treatise on *The Making and Repairing of Roads*, Mr. Leahy states that the power required to move a car upon a level road depends upon the friction of the axles and the resistance to rolling. The friction of the axles is the same in nearly all cases, as long as the load and the car are the same; but the resistance to rolling, having its immediate action at the tyre, must be variable according to the description of road upon which the wheels move.

He proves that the friction at the axle can be represented by the following formula:—

$$P = W\frac{d}{2r} \tan A \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where P is that force applied at the tyre which is just sufficient to rotate the wheel when supported on its axle, where W is the load on the axle,

d the diameter of the axle, $2r$ the diameter of the wheel, and where A is the limiting angle of resistance for the surfaces in contact.

He then goes on to consider the resistance to rolling, which may be due to either or both of two causes, namely, irregularity of surface or yielding of surface over which the vehicle passes.

Dealing with irregularity of surface first, he obtains a formula for the initial effort required to surmount an obstacle.

The formula is

$$P = W\frac{\sqrt{2rh - h^2}}{r - h} \quad . \quad . \quad . \quad . \quad . \qquad (2)$$

where P is the tractive effort required, r is the radius of the wheel, W is the load on the wheel, and h is the height of the obstacle. He further proves that when the tractor, be it horse or motor, is unable to exert this initial effort, the minimum velocity which the vehicle must have to surmount the obstacle is given by

$$V = \sqrt{2g\frac{r}{r - h}\left\{h - \frac{P}{W} \times \begin{pmatrix}\text{length of arc described by centre of}\\ \text{wheel in passing over the obstacle}\end{pmatrix}\right\}} \quad . \qquad (3)$$

V is the least velocity which, together with the draught P, will enable the vehicle to mount the obstacle.

Here he deals with the loss of energy in mounting obstacles, and shows that this loss is given, when h is small, by the following:—

$$\text{Loss of energy} = \frac{WV^2}{g} \times \frac{2h}{r} \quad . \quad . \quad . \quad . \qquad (4)$$

This is lost while the vehicle is moving a distance $= 2l$, say, and hence he shows that the average effort is given by

$$\text{Average effort} = \frac{WV^2}{gr} \times \frac{\sqrt{h}}{\sqrt{2r - h}} \quad . \quad . \quad . \qquad (5)$$

He concludes from these formulæ that the draught on a road whose surface presents a number of unyielding and projecting obstacles varies directly as the square of the velocity, and inversely as the square root of the cube of the size of the wheel. He goes on to say that the draught upon irregular surfaces must be much more than that which has been ascertained, in all cases where the velocity of motion is considerable, because there is no substance perfectly inelastic, and therefore, after striking the obstacle, the wheel will rebound backwards from the obstacle with a velocity proportionate to the relation between the forces of impact and restitution referable to the elasticities of the wheel and the material of the obstruction; moreover, the obstacle when struck will, in many cases, slide to some extent, and thereby weaken the momentum.

He then deals with the tractive effort required for a yielding surface, and states that to a great extent resistance to rolling is due to a continual displacement of a portion of the road material owing to its inelasticity, which, while it allows that material to exert a pressure against the fore part of the wheel, will not permit it to rise behind, and thereby propel the wheel by its reaction. Thus the draught upon a soft surface is much more than if it were upon a hard, unyielding surface.

He then deduces a formula for the draught upon soft surfaces, making two assumptions: first, that surface of road is perfectly inelastic; and secondly, that the resistance to compression varies simply as the depth compressed.

Using the same notation as before, except that h is now the depth to which the wheel sinks, the formula is

$$P = \frac{Wh^2}{\text{Area immersed}} \quad . \quad . \quad . \quad . \quad (6)$$

or further

$$P = \frac{3W}{8} \times \frac{\text{Length immersed}}{\text{Diameter of wheel}} \quad . \quad . \quad . \quad (7)$$

and hence he shows that the draught varies inversely as the cube root of the square of the size of the wheel, or little more than the inverse of the height of the wheel.

He then proceeds to prove that when R is the angle of friction of rolling, A the angle of friction for the surfaces in contact at the axle, d the diameter of the axle, and $2r$ the diameter of the wheel

$$P = W \frac{\sin R + \tan A \frac{d}{2r}}{1 - \sin R \tan A \frac{d}{2r}} \quad . \quad . \quad . \quad (8)$$

He remarks that the deductions of M. Morin are in perfect accordance with the previous theoretical investigations, and alludes to the *Second Report of the Select Committee of the House of Lords* (1833) *upon Turnpike Road Trusts*, where Mr. Macneill has given the following empirical formula for the draught on common roads:—

$$P = \frac{W + w}{93} + \frac{w}{40} + cV,$$

where W is the weight of wagon, w is the load, V the velocity in feet per second, and c a constant, which depends on the surface over which the wagon is drawn.

Mr. Macneill ascertained the value of c for different surfaces as follows:—

$c = 2$ for a timber surface.
$c = 2$ for a paved surface.
$c = 5$ for a well-made broken stone road in a dry state.
$c = 8$ for the like surface covered with dust.
$c = 10$ for the same wet, and covered with mud.
$c = 13$ for a gravel or flint road when wet.
$c = 32$ for the same, very wet and covered with mud.

Leahy then compares the theoretical investigation with experiment, showing in the first place that both agree that springs do not diminish the draught when the motion is so slow as to permit the body of the vehicle to be elevated and depressed just as much as the axle. The fact that the draught over an even, soft surface is not affected by the velocity corresponds with the experiments of M. Morin, but is at variance with the views of Mr. Macneill.

By equation (4) he shows that over hard, irregular surfaces the variation of the draught is as the square of the velocity, and remarks that there is a seeming discrepancy between this conclusion and the results of experiments made under apparently analogous hypotheses, which would regulate the increments of traction by proportional increments of velocity.

It must be remembered, however, that the experiments of M. Morin and others were made upon roads said to be hard, yet not so, in fact, and with elastic machines, whereas had the experiments been conducted upon a perfectly unyielding surface and with a rigid and inelastic machine, there is no doubt that the draught should vary as the square of the velocity, and therefore the conclusion is arrived at that according as the machine and rough roadway approach a state of inelasticity, the more nearly will the draught correspond with this law of variation. Every road presents a different description of surface, and if upon one the draught was not at all affected by the velocity, or varied as V^0 owing to its softness and regularity, and upon another it varied as V^2 owing to its hardness and roughness, surely as there are many intermediate descriptions of surface between these extremes, so also must the draught upon them vary, as some intermediate power, between 0 and 2 of the velocity. Therefore in general, the resistance to rolling must vary as V^n, in which n is the constant suitable to each particular surface, and always lying between 0 and 2; and any accurate empirical expression for the draught upon roads must have V^n as one of its terms.

He then goes on to consider the uniformity of draught, deducing a formula

$$P = W \cos a \left(\tan R + \tan A \frac{d}{2r}\right) + W \sin a$$

for the draught upon an acclivity in which a is the angle of ascent and R the angle of friction of rolling corresponding to any description of surface. Comparing this last equation with that for the draught upon a level road

$$P = W\left(\tan R + \tan A \frac{d}{2r}\right) \text{ nearly,}$$

he concludes by drawing up the following table of uniform draught:—

Table LXIX.

Table of Uniform Draught.

Description of surface.	Rate of inclination.
Ordinary broken stone surface, ...	Level.
Close firm stone paving, ...	1 in 48½
,, timber paving, ...	1 in 41½
,, ,, trackway, ...	1 in 31⅜
,, cut stone trackway, ...	1 in 31⅜
,, iron tramway, ...	1 in 29¼
,, ,, railway, ...	1 in 28½

VII. *The Work of M. Charié-Marsaines.*

M. Charié-Marsaines, inspector of roads and bridges, being struck by the instinctive preference of the farmers in the department Du Nord for paved road, undertook a series of experiments in order to compare paved and macadam roads, as to durability, cost of maintenance, and the maximum load capable of being supported.

Below are the results of his experiments:—

TABLE LXX.

Season.	Description of roads.	Load per horse.	Distance run per hour.	Work per hour in kilogrammetres.	Ratio.
Winter,	Paved	1·306	3·300	4,309,800	1·644
	Macadam	·851	3·080	2,621,080	
Summer,	Paved	1·395	3·500	4,882,500	1·229
	Macadam	1·141	3·480	3,970,680	

The results of Charié-Marsaines' researches are as follows:—

(i.) The wear on the harness is less on paved than on macadam roads.
(ii.) The wear and tear on the vehicles is greater.
(iii.) The lasting power of the horse is much less on macadam roads. A harness lasts six years on paved roads and five on macadam. A vehicle lasts seven years on paved roads and nine on macadam.

These results differ very little from those given by Schwilgué in his experiments performed in 1832 on the roads between Paris and Havre.

VIII. *Experiments by A. Michelin* (1896).

Series of Five Tests made by A. Michelin.

General data for five series of tests were as follows:—

Diameter of iron wheels, . .	front 0·92 m. .	back 1·12 m.
,, pneumatic wheels, .	,, 0·90 m. .	,, 1·20 m.
Weight of iron wheels, ...	,, 58 kg. .	,, 72 kg.
,, pneumatic wheels, . .	,, 39 kg. .	,, 56 kg.
,, brake, empty, iron wheels, ...		577 kg.
,, ,, ,, pneumatic wheels, ...		542 kg.

TABLE LXXI.

Snow Trial on January 5, 1895.

	Iron wheels.	Pneumatics.
	kg.	kg.
Empty carriage (walking), . . .	15·86	11·47
Loaded ,, 150 kg. (,,), . . .	17·83	12·71
,, ,, ,, (trotting), . . .	29·60	15·27
,, ,, 300 kg. (,,), . . .	31·17	17·96

Mud Trial on January 25, 1895.

	Iron wheels.	Pneumatics.
	kg.	kg.
Empty carriage (walking), . . .	16·00	10·50
Loaded ,, 150 kg. (,,), . . .	17·30	12·43
,, ,, ,, (trotting), . . .	19·55	12·97
,, ,, 300 kg. (,,), . . .	23·06	14·16

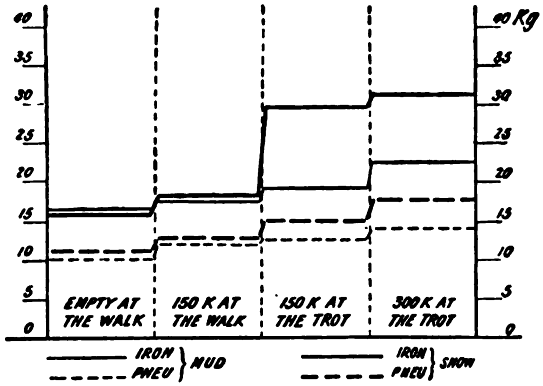

FIG. 147*a*.—First Series (January 1895).

Second Series of Tests, August 1895.

Instead of taking the same running ground (as on the first trials) on the various days, different surfaces were tried under the same conditions of dryness.

TABLE LXXII.

Average for the whole of the Runs.

	Pace.	Iron wheels.	Pneumatic wheels.	If traction of pneumatic = 100 then iron =
		kg.	kg.	
Empty carriage, . . .	Walking	17·42	14·05	124
,, ,, . . .	Trotting	20·41	15·95	128
Heavily loaded, 300 kg., .	Walking	20·75	16·14	128·5
,, ,, ,, .	Trotting	29·70	16·40	181

From the above and fig. 147*b* the advantage of the pneumatic is evident. It is considerably augmented with the speed and the load.

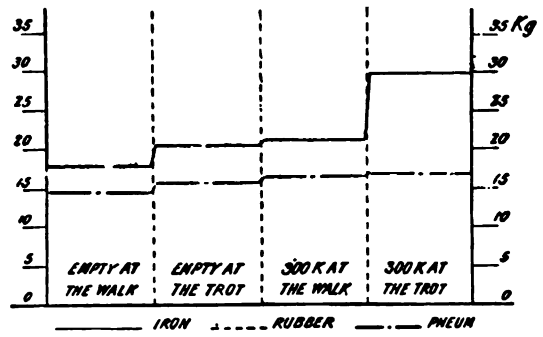

FIG. 147*b*.—Second series (August 1895).

Note.—The number of the figures, tables, and plates in this Appendix is not that of the original pamphlets.

General average obtained for all roads, at all speeds and loadings:—

For iron-shod wheels, ...	22·07 kg.
,, pneumatic ,, ...	15·63 kg.

Michelin found that even upon hard and smooth ground pneumatic tyres gave a greater economy, amounting to about one-third.

Third Series of Tests, November 1895.

More variety in the nature of the roads.

Three trials over each kind of road:—

(*A*) Total length, 40 m.; gradient, 1·5 per cent.; macadam, fairly good, less sound than second series.

(*B*) Total length, 110 m.; good regular pavement; gradient, 1·2 per cent.

(*C*) Badly paved, irregular; gradient, 1·9 per cent.; length, 50 m.

(*D*) Steep gradient, 5·8 per cent.; macadam, in good condition; length, 80 m.

(*E*) Road through vineyards very badly maintained; length, 50 m.

Experiments made at the trot, etc.

Now, if we take the average of all these speeds over the three courses *A*, *B*, and *C*, we have

TABLE LXXIII.

	Iron wheels.	Pneumatics.	Solid indiarubber.
Empty carriages at the trot, ...	20·87	15·45	20·07
Heavily loaded, 300 kg., walking, . . .	22·10	19·87	25·69
Heavily loaded, 300 kg., at the trot, . . .	29·52	20·65	28·62

Walking and trotting.
If traction pneumatics =100
Then traction of iron wheels = 129·4
Traction of solid rubber ,, =132·8

Trotting alone.
Traction for pneumatics =100
,, iron wheels =134·9
,, solid rubber =139·6

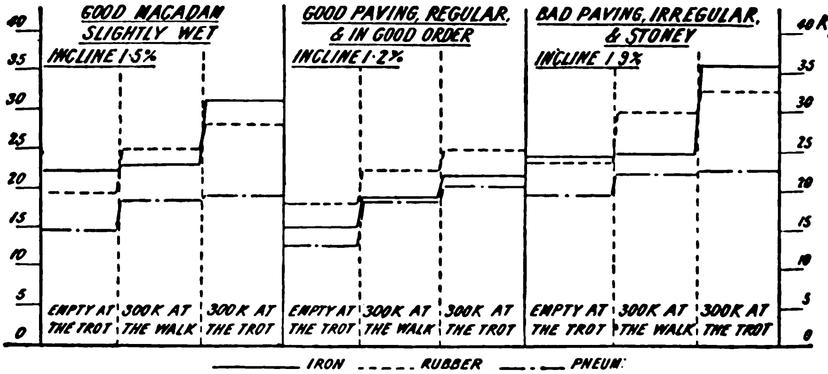

FIG. 148.—Third series of trial (November 1895).

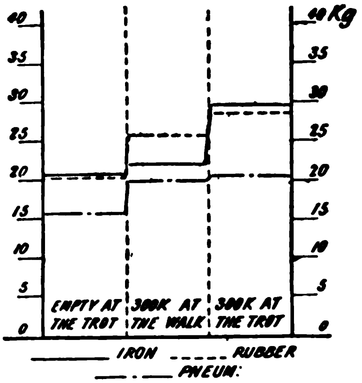

FIG. 149.—Third series (*résumé*).

TABLE LXXIV.

Third Series of Tests, November 1895.

	Empty Carriage at the trot.			Load, 300 kg., at the walk.			Loaded, 300 kg., at the trot.		
	Iron.	Pneus.	Solid.	Iron.	Pneus.	Solid.	Iron.	Pneus.	Solid.
	kg.	kg.	kg.	kg.	kg.	kg.	kg.	kg.	kg.
Course A. Macadam, fairly good condition, slightly damp. Gradient, 1·5 per cent., . . .	22·38	14·34	19·22	22·88	18·79	25·03	31·12(?)	18·9	28·25
Course B. Good regular pavement, dry and clean. Gradient, 1·2 per cent., .	14·83	12·53	17·80	18·89	18·68(?)	22·12	21·30	20·50(?)	24·90
Course C. Bad, irregular pavement, flinty D'Allier. Gradient, 1·9 per cent.,	24·39	19·49	23·20	24·53	22·16	29·92	36·13	22·55	32·70
Course D. Macadam in good condition. Gradient, 5·8 per cent.,	..	..	..	47·73	46·81	49·58	..	..	..
Course E. Macadam, badly kept, wheel ruts. Gradient, 5 per cent., . . .	..	..	..	83·09	56·64	77·91	..	..	..

The results of these tests (shown in fig. 149) only go to confirm the two previous series of tests, and markedly show, the worse the ground the greater the economy in using pneumatics. Tests were not taken with iron wheels over courses D and E, on account of the great shocks destroying the instruments.

Fourth Series of Tests, January 1896.

In the previous experiments errors crept into the results, but this series clears them away.

The normal speed was about 10·5 km. per hour.

TABLE LXXV.

Fourth Series of Tests.

Speeds at the trot, 10·50 km. per hour.		Pneus.	Iron.	Solid.
(A) Pavement tolerably regular. Gradient, 1·8 per cent.	1st. Dry, frosty, . .	19·4	25·9	25·4
	2nd. Liquid mud, slightly sticky, . .	21·65	29·6	28·3
	3rd. Same mud, dried, .	20·25	27·2	26·4
(B) Old macadam, slightly damaged. Gradient, 1·8 per cent.	1st. Dry, frosty, . .	20·6	22·8	24·8
	2nd. Liquid mud, slightly sticky, . .	23·2	31·7	29·2
	3rd. Same mud, dried, .	22·4	28·16	27·5
(C) Good regular pavement; 1·2 per cent.	1st. Dry, . . .	14·8	18·2	18·8
	2nd. Wet, . . .	16·1	19·8	21
(D) Bad and irregular pavement; 1·9 per cent.	1st. Dry, . . .	19·4	29·1	27·8
	2nd. Wet, . . .	22·2	32·4	29·7

If we take 100 as the power necessary to draw the vehicle with pneumatics, then we get—

TABLE LXXVI.

On good pavement with mud slightly sticky,	. Pneumatics	= 100
„ „ „	. Iron wheels	= 136·7
„ „ „	. Solid rubber	= 130·7
Upon bad pavement, dry, ...	. Pneumatics	= 100
„ „ „	. Iron wheels	= 150
„ „ „	. Solid rubber	= 143
Good regular pavement, dry, ...	. Pneumatics	= 100
„ „ „	. Iron wheels	= 123
„ „ „	. Solid rubber	= 127

These results again show the great advantage of pneumatic tyres in all cases.

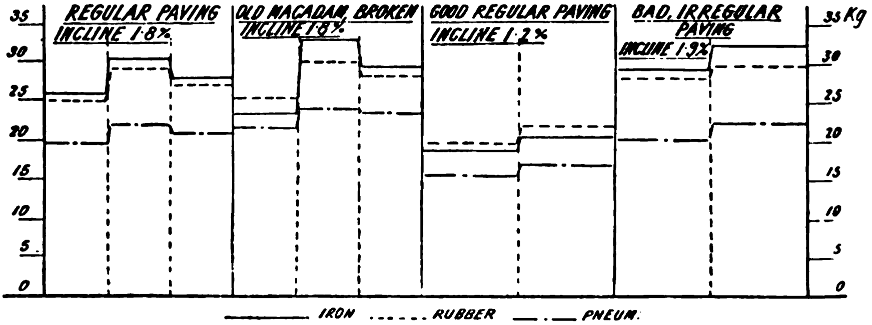

FIG. 150.—Fourth series of trials (January 1896).

Fifth Series of Tests, February 1896.

All the tests hitherto have shown that the economy of pneumatics was more apparent at the trot than at the walk. It can even be said that the force taken by the pneumatic increased but little as the speed went up from walking to trotting, whilst that absorbed by the iron perceptibly increased with the speed.

Experiments were made on a good regular macadam road—length 100 m., gr. 1·5 per cent. Each test was repeated several times with an empty vehicle, from which were deduced the following average speeds:—

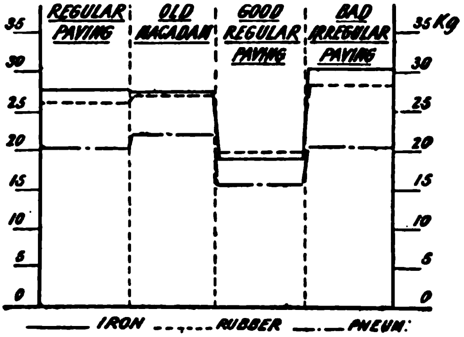

FIG. 151.—Fourth series (*résumé*).

For pneumatics, . . 4·900 km. per hour = walking speed; 10·5 = trotting; 15·12 = quick trot.

For iron, . . . 4·550 km. per hour = walking speed; 10·94 = trotting; 15·12 = quick trot.

The averages of the forces exerted were as follows:—

TABLE LXXVII.

	Walking.	Trotting.	Quick trotting.
For pneumatics, . . .	13·0 kg.	13·5 kg.	13·5 kg.
For iron wheels, . . .	13·8 kg.	17·0 kg.	22·1 kg.

It will be noticed that at the trot and quick trot the results for pneumatics are the same. It appears, then, that whatever the speed may be within reasonable limits, the force absorbed by traction varies but little upon good ground with pneumatic tyres.

Then the advantage of the pneumatic over the iron tyres increases with the speed. If we take 100 as the pneumatic traction, we obtain for the iron traction at the ordinary trot 126, at quick trot 164.

The following conclusions can be drawn from the above experiments:—

(i.) The solid indiarubber tyre is better than the iron in certain cases, especially if the road be sticky, very irregular, or covered with snow, but it becomes inferior to iron if the surface be hard and smooth.

(ii.) Solid tyre vastly inferior to the pneumatic.

(iii.) Pneumatic 50 per cent. better than the iron.

Michelin compared his experiments with those of General Morin by making a series of complementary tests with iron wheels upon good dry pavement as much like the conditions under which General Morin's experiments were performed as possible, with results as follows:—

Walking = 12·9 kg.
Trotting = 8·8 kg.

These, on being compared with General Morin's, will be found in every case below those given by him; this is owing evidently to the better hanging of the vehicle and the better dynamometer.

But if we compare these various forces, taking for example 100 as the force of traction at walking pace, we arrive at the following results:—

TABLE LXXVIII.

		Force calculated after Morin.	Average force from above experiments.
1st Case.—Upon macadam in good condition, dusty,	Walking, .	100	100
	Trotting, .	127	123
	Quick trotting,	152	160
2nd Case.—Good dry pavement,	Walking, .	100	100
	Trotting, .	151	146

The results are almost identical with those of General Morin.

IX. *Extract from the Report of Professor W. C. Unwin, F.R.S., on the Trials of Self-Moving Vehicles at Birmingham, made before the Royal Agricultural Society*, 1897.

Some experiments were made on the competing vehicles to determine the vehicle friction.

The method adopted was to allow the cars to run down hill by gravity (the motor being idle) and noting the speed acquired and the distance in which they came to rest.

The cars, fully loaded, were taken to a hill on the road between Bassett's Pole and Bonehill. This portion of the road was levelled and marked out in 100-foot distances.

The total weights of the cars and loads in these trials were the following:—

Daimler, ...	2·43 tons.
Lancashire, ...	6·49 ,,
Chiswick, ...	6·57 ,,

Method of Trials.—Each car was brought to one of the marked distances on the descending gradient, generally the point 300 feet from A, but in trial 3 at 400 feet from A. The car was then gently started from rest and allowed to descend the hill by gravity. As it passed over the 200-foot length from B to C the time of passage was taken. The car was allowed to come to rest, stopping generally at a point beyond C, but in two trials a little short of C. From the speed over the base B C one measure of the friction can be obtained. The mean gradient from start to stop is another measure.

The following formula was used for calculating the friction from the speed observations:—

$$f = \frac{h - \frac{v^2}{2g}}{s}$$

where $2240f$ is the friction of the car reckoned in lb. per ton, h the fall in feet from the point where the car started to the middle point of the base B C, and s the distance from the starting-point to the middle point of B C.

$1/f$ is the gradient due to the friction; that is, the greatest gradient on which the car would stand without moving, or if put in motion would run without acceleration.

The following table (LXXIX.) gives the values of the friction calculated from the observations:—

TABLE LXXIX.

Gravity Trials. Speed Observations.

No. of run.	s. Distance from starting-point to middle of base B C, in feet.	l. Length of base B C for which time of passage was taken, feet.	t. Time over base, sec.	$l/t = v$. Mean speed over base, foot per sec.	h. Fall from starting-point to middle of base B C, feet.	$\frac{v^2}{2g}$	f. Friction of vehicle in lb. per ton.	f. Gradient corresponding to friction.	Mean.
				Daimler Motor Company, London.					
2	400	200	10·0	20·00	16·77	6·23	58·9	1 in 38	1 in 45
4	300	200	11·8	16·94	10·25	4·46	43·2	1 in 52	
3	400	200	9·4	21·27	16·77	7·04	54·4	1 in 41	
				Lancashire Steam Motor Company, Leyland.					
5	384	168	21·2	7·93	16·77	0·98	92·0	1 in 24	1 in 25
7	396	192·5	22·0	8·75	16·77	1·19	88·0	1 in 25	
9	400	200	18·0	11·11	16·77	1·92	83·1	1 in 27	
8	400	200	11·4	17·54	16·77	4·70	67·0	1 in 33	
				Steam Carriage and Wagon Company, Chiswick.					
10	400	200	14·4	13·89	16·77	3·00	77·0	1 in 29	1 in 29
11	400	200	15·0	13·33	16·77	2·76	78·4	1 in 29	

Note.—In Run 8 with the Daimler car the engine but not the gearing was disconnected. In Run 8 with the Leyland car the engine was disconnected.

It will be seen that the Daimler car had the least friction, viz., $\frac{1}{45}$th of its weight, or 51 lb. per ton. The Thornycroft car had a friction of $\frac{1}{29}$th of its weight, or nearly 78 lb. per ton. The Leyland car had a friction of $\frac{1}{25}$th of its weight, or nearly 88 lb. per ton. With the engine disconnected the Daimler car had a friction amounting to $\frac{1}{41}$ of its weight, and the Leyland car had a friction amounting to $\frac{1}{33}$rd of its weight, or 67 lb. per ton.

From the difficulty of getting the speed quite accurately, and also to some extent because the method of calculation is approximate, probably these results are not quite so trustworthy as those obtained in the following manner, in which the friction is calculated from the distance from starting to stopping.

Friction calculated from distance of running from starting to stopping. Let s be the total distance the car ran, and h the fall of level in that distance. Then h/s is the gradient due to friction, and corresponds to i/f in the previous calculation.

A table of the results of the observations calculated in this way differed only slightly from the previous results.

X. *Experiments by Professor H. S. Hele-Shaw, F.R.S., for the Royal Lancashire Agricultural Society*, 1897.

Professor Hele-Shaw made a number of experiments for the above Society at their show held at Southport, 1897. Among other results he obtained the tractive force for agricultural wagons and carts, on turf and roads.

The following is a brief summary of the results obtained:—

TABLE LXXX.

	Diameter of wheels.		Width of tyres.		Weight of wagon or cart.	Load in tons.	Tractive force per ton of load on turf.	Tractive force per ton of load on road.
	Fore.	Hind.	Fore.	Hind.				
	in.	in.	in.	in.				
Agricultural wagons, .	39	42	4	4	2142	3	235	148
,, ,, .	39	42	4	4	1895	3	277	125
,, ,, .	37	41	4	4	1813	3	289	139
,, ,, .	36	40	4	4	1752	3	227	170
Agricultural cart, .	65	...	3	...	1281	1½	269	116
,, ,, .	60	...	4¾	...	1435	1½	260	147
,, ,, .	59	...	4½	...	1235	1½	332	111
,, ,, .	59	...	4½	...	1278	1½	240	109
,, ,, .	56	...	4	...	1148	1½	235	108
,, ,, .	58	...	4	...	1330	1½	253	130
,, ,, .	57	...	4½	...	1379	1½	248	153

XI. *Investigations of Ira O. Baker, M.Am.Soc.C.E.* (1902).

The resistance to traction of a vehicle upon the road consists of three independent elements: I. Axle friction; II. Rolling resistance; and III. Grade resistance. Nothing need here be said about grade resistance, since it is perfectly understood that it is equal to 20 lb. per ton for 1 per cent. of grade.

I. *Axle friction.*—It has nothing to do with the surface of the road. The coefficient of friction varies with the material of the journal and its bearings, and with the lubricant. It is nearly independent of the velocity, and according to the author's experiments seems to vary inversely as the pressure.

For light carriages when loaded the coefficient = 0·020 * of the weight on axle.
For heavier ,, ,, ,, = 0·015 * ,, ,,
For American thimble skein wagon ,, = 0·012 * ,, ,,
* The above figures assume good lubrication.

If there is a deficiency of lubricant, these figures are 2 to 6 times greater. General Morin's value for axle friction was 0·065; this difference is probably due to the better mechanical construction of the present day. The tractive force required to overcome the axle friction is about 3 to 3½ lb. per ton of the weight on the axle for ordinary wagons, and from 3½ to 4½ lb. for wagons with medium-sized wheels and axles.

II. *Rolling resistance.*—The resistance of a wheel to rolling is due to the yielding or indentation of the road, which causes the wheel to be continually climbing an inclination. The resistance is measured by a horizontal force necessary at the axle to lift it over the obstacle, or to roll it up the inclined surface. The rolling resistance varies with:—(i.) The diameter of the wheel; (ii.) the width of the tyre; (iii.) the speed; (iv.) the presence or absence of springs on the vehicle; (v.) the nature of the road surface.

(i.) *The diameter of the wheel.*—The rolling resistance varies inversely as some function of the diameter of the wheel, since the larger the wheel the less the force required to pull it over the obstacle.

The results of the experiments are shown in Table LXXXI., data as follows:

The three sizes of wheels used: (44″ in front and 56″ hind wheels) = 50″ wheels.
,, ,, ,, (36″ in front and 40″ hind wheels) = 38″ wheels.
,, ,, ,, (24″ in front and 28″ hind wheels) = 26″ wheels.
The load being 1¾ ton of 2000 lb. per ton, and with tyres 6″ wide.

TABLE LXXXI.

Effect of the Size of Wheels on Traction.

Description of the road surface.	Tractive force, lb. per ton.		
	Mean diameter of front and rear wheels.		
	50 in.	38 in.	26 in.
Macadam, slightly worn, clear fair condition, . .	57	61	70
Gravel road, dry, sand 1 in. deep, loose stones, . .	84	90	110
,, ,, up grade 2·2 per cent., ½ in. wet sand, frozen below, ...	123	132	173
Earth road, dry and hard, ...	69	75	79
,, ,, ½ in. sticky mud, frozen hard below, rough,	101	119	139
Timothy and bluegrass sod, dry, grass cut, . . .	132	145	179
,, ,, ,, wet, spongy, . . .	173	203	281
Cornfield: flat culture; across rows, dry, . . .	178	201	265
Ploughed ground; not harrowed, dry, cloddy, . .	252	303	374
Average value of the tractive power, . .	130	148	186

Morin **concluded that the resistance varies inversely as the first power of the diameter of the wheel.**

Dupuit **that it varies inversely as the square root.**

Clark **that it varies inversely as the cube root.**

Baker **that it varies very nearly inversely as the square root of the mean diameter.**

(ii.) *Width of tyres.*—If the wheel cuts into the road, the traction is thereby increased; but for surfaces where there is little or no indentation the width of tyre has practically no effect upon the traction (see Tables LXXXII. and LXXXIII.).

TABLE LXXXII.

Effect of the Width of Tyres (load 1 *ton).*

Description of the surface.	Resistance to traction lb. per ton.	
	Width of tyres.	
	1¼ in.	6 in.
Broken stone road.—Hard, smooth, no dust, no loose stones, nearly level,	121	98
Gravel roads.—Hard and smooth, few loose stones, size of black walnuts,	182	134
,, Hard, no ruts, the large quantity of sand prevented packing,	239	157
,, New gravel, not compact, dry,	330	260
,, Wet, loose sand, 1 in. to 2½ in. deep,	246	254
Earth roads.—Loam, dry, loose dust, 2 in. to 3 in. deep,	90	106
,, ,, ,, hard, no dust, no ruts, nearly level,	149	109
,, ,, stiff mud, drying on top, spongy below,	497	307
,, ,, mud, 2½ in. deep, very sticky, firm below,	251	325
,, Clay, sloppy mud, 3 in. to 4 in. deep, hard below,	286	406
,, ,, dry on top but spongy below, narrow tyres cut in 6 in. to 8 in.,	472	422
,, ,, dry on top but spongy below,	618	464
,, ,, stiff, deep mud,	825	551
Mowing land.—Timothy sod, dry, firm, smooth, narrow tyres cut in 1 in.,	317	229
,, Timothy sod, moist, narrow tyres cut in 3½ in.,	421	305
,, Soft and spongy, grass and stubble 3 in. high, narrow tyres cut in 6 in.,	569	327
Pasture land.—Bluegrass sod, dry, firm, smooth,	218	156
,, ,, soft, narrow tyres cut in 3 in.,	420	273
,, ,, narrow tyres cut in 4 in.,	578	436
Stubble land.—Corn stubble, no weeds, nearly dry enough to plough,	631	418
,, Corn stubble, some weeds and stalks, dry enough to plough,	423	362
,, Corn stubble in autumn, dry and firm,	404	256
Ploughed land.—Freshly ploughed, but not harrowed, surface rough,	510	283
,, ,, harrowed, smooth and compact,	466	323

(iii.) *Effect of speed.*—The rolling resistance increases with the velocity, owing to the effect of the shocks or concussions produced by the irregularities of the road surface. It requires from two to six or eight times as

TABLE LXXXIII.

Effect of the Width of Tyres on Traction.

Description of the road surface.	Resistance to traction in lb. per ton of 2000 lb.									
	44 in. and 46 in. wheels.				44 in. and 54 in.		42 in. and 46 in.		44 in. and 54 in.	
	Tyres.				Tyres.		Tyres.		Tyres.	
	1½ in.	4 in.	1½ in.	4 in.	1½ in.	4 in.	1½ in.	3 in.	1¾ in.	3 in.
Sod, ...	...	...	...	...	...	...	283	239	189	228
Roads. Earth hard, .	...	108	...	...	...	...	152	152	114	114
,, ,, muddy,	...	243	268	304	236	254	...	...	265	228
Sand. Hard, . .	199	162	171	164	141	168	...	...	...	...
,, Deep, . .	371	351	...	...	...	...	...	...	...	...
Gravel, . . .	...	...	98	117	83	80	...	...	66	76
Wood block ; round, .	51	49	61	70	35	46	...	54	28	38

TABLE LXXXIV.

Effect of Speed on Tractive Force (after Morin).

Description of the road surface.		Stage coach.			Carriage.		
		Walk.	Trot.	Fast trot.	Walk.	Trot.	Fast trot.
Broken stone road.	Good condition, dry, compact, ...	42	49	50	41	48	49
,,	Very firm, large stone visible,. . . .	59	75	81	58	73	81
,,	Little moist, or little dirty,	49	75	88	48	74	88
,,	Firm, little soft mud, .	77	92	100	76	91	99
,,	Firm, ruts and much mud,	95	108	117	93	108	116
,,	Portions worn out, thick mud, ...	112	127	134	110	126	132
,,	Much worn, mud, ruts 3 in. deep, ...	146	161	169	145	160	168
,,	Very bad, rough, ruts 4 in. deep, ...	164	180	...	162	202	...
Stone block pavement.	Very smooth, narrow joints, ...	32	48	55	31	47	54
,,	Fair condition, dry, . .	35	52	61	34	51	67
,,	Moist, covered with dirt, .	35	49	56	44	60	67

TABLE LXXXV.—*Traction of Different Vehicles on Various Level Roads, at 3 miles per hour, in lb. per ton of 2000 lb. (after General Morin).*

Description of the Road Surface.		No springs.						On springs.		
		Gun carriage.	Freight cart.		Artillery wagons.	Freight wagons.		Stage coach.	Carriage.	Wagon.
		Tyres 4·5". Axle 3". Diameter of wheels 60".	Width of tyres 4·5". Diameter of axle 2·5". Diameter of wheels 64".	Width of tyres 4·5". Diameter of axle 2·5". Diameter of wheels 80".	Tyres 3". Axle 3". Diameter of wheels 45" and 60".	Width of tyres 4·5". Diameter of axle 2·5". Diameter of wheels 36" and 60".	Width of tyres 4·5". Diameter of axle 2·5". Diameter of wheels 44" and 78".	Tyres 4·5". Axle 2·5". Diameter of wheels 36" and 56".	Tyres 3". Axle 2". Diameter of wheels 36" and 56".	Tyres 2·5". Axle 2". Diameter of wheels 50" and 58".
Grass plat.—	Very firm and dry, . . .	72	...	...	82	...	...	...	...	...
,,	Moderately firm, . . .	87	...	...	100	...	...	...	...	...
,,	A little moist, ...	98	...	...	...	...	...	...	...	...
,,	Slightly wet, ...	140	...	...	160	...	...	...	...	...
,,	Very wet, no water on surface, .	...	...	...	260	...	...	...	..	...
Earth road.—	Very good, nearly dry, . .	57	55	44	66	74	63	77	76	64
,,	Covered with untrodden snow, .	109	105	84	125	140	120	146	...	123
Gravel road.—	1¼"–1½" loose gravel on firm earth,	147	143	114	169	190	163	198	198	168
,,	2"–2½" ,, ,,	172	168	134	198	225	192	233	233	198
,,	4"–6" ,, ,,	185	180	144	216	241	206	250	250	12
,,	4"–6" ,, and fine sand,	196	190	153	247	251	217	267	290	225
Broken stone road.—	Good condition, dry and compact,	32	30	24	37	40	34	42	41	35
	Very firm, large stones visible, .	37	35	28	43	47	40	49	48	41
,,	Little moist or little dirty, .	45	43	34	52	57	49	59	58	50
,,	Firm, little soft mud, . .	57	55	44	66	74	63	77	76	64
,,	Ruts and much mud, . .	70	68	54	81	90	78	95	93	79
,,	Portions worn out, thick mud, .	83	80	64	96	107	92	112	110	94
,,	Much worn, ruts 3", thick mud,	109	105	84	126	140	120	146	145	123
,,	Very bad, ruts 4", very rough, .	121	118	94	140	157	134	164	168	139
Stone block pavement.—	Very smooth, narrow joints, .	25	23	18	29	31	26	32	31	26
	Fair condition, dry, . .	27	25	20	31	34	29	35	34	29
,,	Moist, covered with dirt, . .	34	33	26	40	43	37	45	44	38
Plank road.—	Thick oak, bridge floor, . .	37	35	28	43	47	40	49	48	41

much force to start a vehicle as to keep it in motion at two to three miles an hour. The extra force required is due to:—(1) During the stop the vehicle has partly sunk into the road; (2) axle friction is greater at starting than after motion has begun; (3) energy is consumed in accelerating the load (see Table LXXXIV.).

(iv.) *Effect of springs.*—Springs decrease the traction by decreasing the concussions due to the irregularities of the ground, and are therefore more effective at high speeds than low, and on rough roads than on smooth.

TABLE LXXXVI.

Tractive Resistance of Level Pavements.

Description of pavement.	lb. per ton 2000 lb.
Asphalt.—Clean, smooth, no cracks, 52° F., ...	37
,, ,, ,, ,, 84° F., ...	70
,, ,, ,, ,, 42° F., ...	34
Brick.—3 in. × 9 in. bricks on concrete, corners rounded, sand filler, not worn, ...	17
,, 3 in. × 9 in. bricks on concrete, but newer and covered with ½ in. dust, ...	31
,, 3 in. × 9 in. bricks on concrete, but cement filler, just completed, ...	22
,, 2¼ in. × 8 in. brick on concrete, pitch filler, new, . . .	24
,, 3 in. × 8 in. brick on gravel and cinders, sand filler, corners not rounded, ...	37
,, 2½ in. × 8 in. brick on sand and old macadam, tar filler, new,	25
Granite block.—Smoothly dressed 3 in. × 9 in. blocks on concrete joints, ¼ in. tar filler, not worn, ...	29
,, Smoothly dressed, on concrete, pitch filler; new, .	30
,, Ordinary granite, 10 years' wear, ...	36
Macadam.—Granite top, no dust, no mud, ...	18
Plank road.—Oak plank, 3 in. × 12 in., nearly new, ...	32
,, Same as above, after worn down ¼ in. in many places, clean, ...	38
,, As above, covered with ½ in. fine loose dirt, . . .	40
Steel wheelway.—8 in. 11¼ lb. channel, on 2 in. × 8 in. pine, on macadam, covered with ⅛ in. powdered stone, . .	40
,, ,, Same as above, scraped clean with a shovel, . .	19
,, ,, ,, ,, covered with ⅛ in. fine dust, . .	28
Wood block.—Rectangular blocks, 3 in. × 12 in., considerably worn, .	36
,, ,, Round cedar block, covered with ½ in. silica pea gravel,	90
,, ,, ,, ,, ,, ,, ,, ¾ in. crushed gravel, .	50
,, ,, ,, ,, ,, clean, blocks slightly convex on top,	53
,, ,, Round cedar block, 2 in. plank, 2 in. sand, clean, not worn, ...	37
,, ,, Same as above, clean, slightly worn, ...	51
,, ,, ,, ,, ,, considerably worn, . . .	54

3, 4 and 5 with wheels averaging 42½ in. diameter, the remainder 47 in.

(v.) *Different road surfaces.*—The tractive force was obtained by a Baldwin dynagraph. The instrument consists of two long flat springs fastened together at their ends, and having their centres farther apart than their ends. One end of the apparatus is attached to the wagon, and the other to the team. The pull of the team causes the centres of the flat springs to approach each other. One spring supports a graduated disc, and the other is connected to an index arm which is pivoted at the centre of the graduated disc. From one end of this index arm the pull can be read directly from the graduation. There are two extra index arms, one to indicate the maximum power developed and the other to indicate a rough average. The end of the index arm, opposite the graduated arc, records the amount of traction upon a strip of paper which is wound from one cylinder to another by clockwork (see Tables LXXXV. and LXXXVI.).

XII. *Summary of the Opinions of Various Writers on the Effects of Traction on the Level of the Independent Elements of Road Resistance.*

TABLE LXXXVII.

Tractive Force.

Authority.	Date.	Load.	Diameter of wheels.	Width. of tyres.	Nature of tyres.	Velocity.	Springs.	Deterioration of roads.
Edgeworth.	1808	..	..	..	..	..	On rough roads increase of efficiency by one-third at 8·8 kilos per hour.	..
Corréze and Manès.	1832	..	..	..	..	Increases with.	Diminishes on roads having irregular surfaces.	Proportional to load width of tyre and speed.
Coriolis	..	Directly proportional to the ¾th power.	Inversely as the cube root of the square.	Inversely as the square root.	..	..	..	..
Morin	1837-1842	Proportional.	Varies inversely as the first power.	Nearly independent for macadam and paved roads for sizes above ·08 m. to ·10 m. On compressible roads, such as loose earth, sand, gravel and new macadam, traction decreases as width increases, the proportion depending on the condition of the road.	Iron tyres only were experimented with.	Independent on soft ground, such as soil, sand, etc., with or without springs. Increases for paved or macadam roads.	No effect on soft ground such as soil, sand, etc.	Inversely proportional to diameter of wheels.
Dupuit	..	Proportional.	Varies inversely as the square root.	Independent.	..	Independent on macadam and smooth roads; generally increases on paved roads.	Diminishes on paved roads. Very little influence on macadam roads.	..

VI.

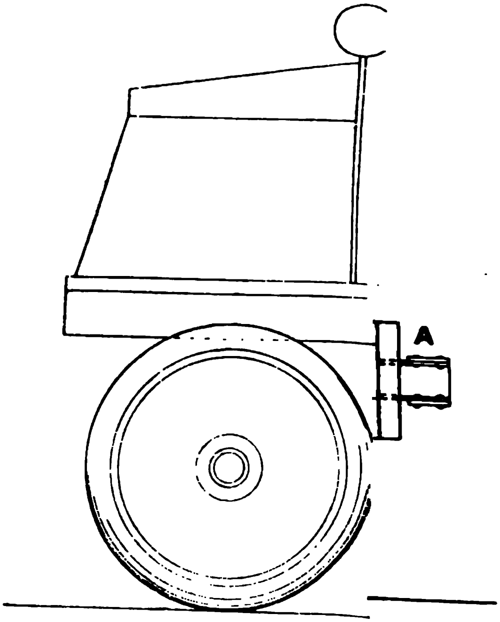

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TABLE LXXXVII.—*continued.*

Authority.	Date.	Load.	Diameter of wheels.	Width of tyres.	Nature of tyres.	Velocity.	Springs.	Deterioration of roads.
Leahy	1847	Proportional.	Inversely proportional.	Independent.	..	Independent on soft surfaces. Varies as the second power on perfectly hard irregular roads.	Useless at very slow speeds.	..
Michelin	1896	..	..	..	Solid rubber tyre is better than iron in certain cases, especially if the road be sticky, very irregular, or covered with snow, but it is inferior to iron if road be hard and smooth. Pneumatics 50 per cent. better than iron.	..	..	..
Clark	..	..	Inversely as cube root.	..	..	..	..	..
Baker	1902	..	Very nearly inversely as the square root of the mean diameter.	Almost independent.	..	Increases with.	Diminishes, more effective at high speeds than at low speeds.	..

XIII. *Description and Drawings of the New Dynamometer made for the British Association Committee to carry on the Researches.*

The general arrangement of the new dynamometer made for the Committee to carry out the researches on road resistance is shown in Plate VI. The apparatus comprises a castor frame, A A, in which can be mounted the wheel, B, to be experimented on, a system of levers, C C, for transmitting to a small plunger, E, the pull exerted on the wheel, and a recording pressure gauge for registering the same, together with a recording tachometer.

Frame.—The castor frame is of wrought iron, and is rectangular in shape. Its sides are of channel iron, 4 inches by 2 inches by ¼ inch, and are fastened together at the end by wrought-iron plates, ½ inch thick and 5 inches wide, bolted on at the top and bottom. The total length of the frame is 6 feet, and as the end plates have three sets of holes drilled in them, it can be arranged so that the sides are 10 inches, 14 inches, or 16 inches apart, to suit the various widths of wheels to be experimented upon.

Axle and Springs.—The axle of the experimental wheel is mounted on springs, one under each side of the castor frame. The springs are 3 feet 2 inches centres, and each consists of six plates $2\frac{1}{4}$ inches by $\frac{5}{16}$ inch. When light wheels and loads are used these springs are reduced to a suitable strength by the removal of some of the plates. If desired the axle can be mounted on the frame without springs.

Loading.—The method of loading the frame is by bolting a series of 28-lb. cast-iron weights to the channel iron sides. These weights are each 2 inches thick, so that when the scroll irons for the springs do not interfere, 52 or so can be affixed, thus giving a load of 13 cwt., besides the weight of the frame and wheel. This would correspond to a load of about $3\frac{1}{4}$ tons on a four-wheeled vehicle. This arrangement of loading enables the weight to be varied by steps of 56 lb., the weights always being arranged at equal distances on either side of the centre, so that the frame will never be out of balance.

Attachment of Frame to Car.—This frame is fixed to the levers which transmit the force to the water by a swivel joint, D, so that it is quite free to vibrate or bounce vertically as over rough ground; and it can also follow the car freely round any curve without in any way affecting the records, but it is held so that the experimental wheel is always vertical.

Levers.—The system of levers is so arranged that the frame can be raised or lowered to suit any diameter of wheel or any angle of draught without in any way altering the leverage of the mechanism. They may be described as follows.

A pair of similar bell-crank levers is mounted on a fulcrum which is capable of being raised or lowered in a vertical slot formed in a steel casting mounted firmly on the back of the car. The distances from this fulcrum to the ends of levers are respectively 14 inches and 28 inches, the longer arm being normally vertical, while the other is horizontal. To the shorter arm are attached two parallel vertical steel rods whose length is capable of adjustment. These rods serve to transmit the pull on the frame to one end of a small horizontal lever, the hydraulic plunger being at its other extremity. The fulcrum of this lever may be moved to either of four positions, such that the pressure on the plunger is equal to one, two, four, or eight times the pull exerted on the castor frame. By having this arrangement it is possible to use the apparatus through a very wide range of experiments, say, for tractive efforts of from 5 to 500 lb.

Plunger.—The plunger E, which is 2·6 inches diameter, presses upon a rubber diaphragm enclosing a space filled with water, and it is the pressure exerted on this water that is autographically recorded. Two pipes are connected to the water space, one for transmitting the pressure to the gauge G (Plate VI.), the other being used for filling the system. An ordinary rubber bulb off a motor horn is filled with water and connected to this latter pipe, so that when the bulb is squeezed by the hand the water is forced through the system, and out of a small hole in the end of the Bourdon tube. By this means all the air is expelled, and when sure that such is the case the system is closed and the water retained.

Recording Apparatus.—The recording apparatus was placed in the hands of Messrs. Schaffer & Budenburg, Ltd., Manchester, who have turned out a very good instrument. This apparatus is a combined recording pressure-gauge G and tachometer H (Plate VII.), mounted on one base and recording on the same horizontal drum K, which carries a band of paper, L L, $8\frac{1}{2}$ inches wide, the graph of tractive effort-space

being at one side of the paper while that of velocity-space is at the other side. This drum is driven off the tachometer spindle, and its motion, therefore, is in accordance with the motion of the car, a length of 10·3 feet of the paper corresponding to a mile of road. The makers have worked out a very neat parallel motion, so that the ordinates of both graphs are straight.

The instrument is mounted in a rain-proof glass case, supported on a pneumatic cushion, N, the drive to the drum and tachometer being through a flexible shaft. This arrangement has worked very well, fairly steady curves being obtained even over rough roads at high speeds. Stops are provided to prevent too great a movement of the levers, thus ensuring against undue shocks on the gauge.

If found necessary an arrangement can be attached for marking seconds on the paper.

A revolution counter is provided for obtaining independently the revolutions of the experimental wheel: this will act as a check on the record.

XIV. *Nature and Scope of the Experiments by the Committee.*

Experiments will be conducted to determine the relation between the tractive effort and the following, viz., load, diameter of wheel, width and section of tyre, hardness of tyre (in the case of pneumatics), effect of springs, and velocity for every type of road under all circumstances, and any other relations that may be suggested during the progress of the work.

In performing an experiment a given type of wheel is mounted in the frame and a run made over a piece of road of the desired type. Since the two graphs are side by side the relation between tractive force and velocity can be seen at every point of the run, and from those portions of the graph where the velocity is constant and of the required value a mean tractive effort can be obtained. After a number of experiments have been performed, curves can be plotted and empirical formulæ deduced for the various relations.

The relative values of the various roads are being compared by taking viagrams by means of a special instrument, the viagraph, kindly lent by the inventor, Mr. J. Brown, F.R.S., of Belfast.

XV. *The Work of the Committee presented at the Meeting.*

After a good deal of delay, due to various causes, the dynamometer was at length completed about August 20. It was then calibrated in the following manner. The car and dynamometer were placed on a smooth horizontal floor with a 40-inch lurry-wheel mounted in the frame. The car itself was prevented from moving backwards, and a given load was attached to a wire fixed to the wheel at the top and passing over the tyre, so that it hung vertically, thus tending to pull the frame away from the car. After a load was applied the apparatus was shaken to prevent it from sticking in any way, the paper meanwhile being uniformly moved until the pencil of the pressure-gauge had moved to its position of equilibrium. This was done with every reading. When the leverage of 8 to 1 was being calibrated, increments of 2 lb. were used in almost every case from 0 to a total of 82 lb. For the 4 to 1 leverage increments of 14 lb. were taken, after 14 lb. had been reached, the highest reading being 168 lb., the 2 to 1 leverage had increments of 14 lb., the highest being 280 lb., while the 1 to 1 leverage had increments of 28 lb. up to a total of 530 lb. Calibration curves were drawn for each leverage, and scales were drawn from these curves. Nine large wall-diagrams were shown at the meeting, the first being the calibration curve for the dynamometer when the 4 to 1 leverage was in use.

The tachometer was calibrated by driving it with an electric motor. The exact time of three revolutions of the drum was taken by means of a stop-watch for readings of 10, 15, 20, 25, and 30 miles per hour on the scale (three revolutions of the drum correspond to 315 revolutions of tachometer spindle). The mean diameter of the back wheels of the car was taken as 842 mm. when the car was normally loaded and tyres normally inflated; the diameter of pulley on back axle is 225 mm.; diameter of tachometer pulley 75 mm. Working out the speed from this data, the calibration curve shown on wall-diagram No. 2 was obtained, thus showing that the scale readings are reliable. It might be argued that if the driving wheels of the car slipped on the road, the tachometer is really reading higher than it ought to do; but as readings are only used for which the velocity is constant very little slip may be expected; and since it is impossible for the driving belt of the tachometer to slip, thus giving too low a reading, it is not too much to assume that these errors will balance each other to some extent.

The method of operating the dynamometer and performing a trial is as follows. The castor frame is pushed towards the car, so that the ram is as far out of the cylinder as possible; the bulb, having been previously filled with water, is squeezed by the hand, so that the water is forced through the cylinder, through the connecting tubing, and out through the opening in the end of the tube of the pressure gauge. This method of filling ensures the removal of all air. When all the air has been removed the cocks at each end of the system are closed. The stops have now to be adjusted so that the maximum pressure of the water cannot exceed 100 lb. per square inch, or else the gauge might be destroyed. After the adjustments are satisfactory a run is made to some given point over a given piece of road whose surface is of the desired type, a return run being made over the same road back to the starting-point. By taking the mean values for the double journey, out and return, the effect of inclines is eliminated. The load is then increased and the route traversed again, and so on. For the first few experiments for a given load the speed was given a succession of values ranging from six to fourteen miles an hour, all in the inward run, just remaining constant at each speed for a sufficient distance to give a definite reading on the paper, and during the return journey the speeds were gone through in the reverse order, so that as near as possible the same piece of road was traversed at the same pace in each direction, this procedure being repeated for each load. This was not found very satisfactory on the whole, so that for the succeeding experiments a given space was covered both on the outward and return journeys at a definite speed. The same journey was then traversed under a higher constant speed, and so on, until sufficient readings had been obtained to give a curve. This process was gone through for each load. This method, although slower than that tried at first, was found to give much more satisfactory results. As the dynamometer has only been completed such a short time, the trials are as yet only preliminary; the general results, however, tend to confirm those of previous investigators. The diagrams shown at the meeting have not been reproduced here, it being thought unnecessary, as they will have to be all reproduced in the next report, by which time the striking results brought out by them, if duly confirmed, will by repeated experiment have been placed beyond question.

Experiments.

The first experiment was conducted near Sefton with an ordinary light lurry wheel, 40 inches diameter, having a 3-inch iron tyre, slightly rounded in section. This wheel was kindly lent by Messrs. T. Coleburn & Son, Cherry Lane, Walton, who have also promised to lend different sizes of wheels of a similar type for the experiments.

The wheel was mounted on a pair of springs, 3 feet 2 inches centres, each having six plates 2¼ inches by $\frac{5}{16}$ inch. Three different runs were made with loads of 3½, 5½, and 8½ cwt. respectively, with velocities ranging from 6 to 14 miles per hour. The results obtained, however, were not very satisfactory.

The second series of experiments were made with the same wheel and springs as were used in the first series, viz., light lurry wheel, 40 inches diameter, having 3-inch tyre slightly rounded in section, the springs each consisting of six plates 2¼ by $\frac{5}{16}$ inch. The route was a portion of Regent Road, Bootle, which runs parallel to the line of docks, and is quite level. It is paved with setts, 6 inches by 3 inches, with a 1-inch gap, and has a regular but fairly rough surface. Two runs were made with loads of 6 and 8½ cwt. respectively at speeds at from 5 to 14 miles per hour.

A wall-diagram was exhibited showing the results of the series of experiments. For both loads the tractive effort increased rapidly with the velocity, and at the same time was fairly proportional to the load. A diagram showed the results plotted as tractive effort per ton.

The third series of experiments were made with a pneumatic-tyred wheel, 24 inches diameter, 2¾ inches tyre. The springs, 3 feet 2 inches centres, each consisted of two plates 2¼ inches by $\frac{5}{16}$ inch. This trial was made on September 5 on a level stretch of macadam road passing through Ince Woods, near Sefton. The surface was in fairly good condition, slightly wet in places.

With these series of experiments a run was made with a given load at a constant speed to a spot about ½ mile from the starting-point. The return run was made at the same speed. With the same load a higher speed was then taken, and so on, so that for each load readings were taken at about 6½, 8, 10, and 14 miles per hour. This method of procedure was followed for each load carried. The leverage used was 4 to 1, and the loads were respectively 315, 427, 539, and 651 lb.

Wall-diagram No. 5 showed the tractive effort velocity curves for each load. It was noted that the tractive effort was directly proportional to the load, but increased very slightly with the velocity. This was what was observed by M. Michelin in his experiments.

Wall-diagram No. 6 showed a curve plotted between tractive effort and load for the above. It being a straight line showed that the tractive effort was directly proportional to the load.

Wall-diagram No. 7 gave the four curves of diagram No. 5 plotted as tractive effort per ton.

A specimen of the graph was reproduced on a large scale as a wall-diagram to show the nature of the curve obtained. In the experiments which have been made as yet only level roads have been tried; and it was not possible on a level road, dragging the wheels behind, to experiment satisfactorily with speeds of more than 15 miles per hour with the present car. For higher readings than this, experiments will be conducted on an incline of such a gradient that a positive reading is recorded on the dynamometer, so that to find the pull on the wheel for the velocity it is only necessary to add to the registered pull the component of gravity parallel to the surface in question. By this means it will be possible to reach speeds up to 30 miles per hour.

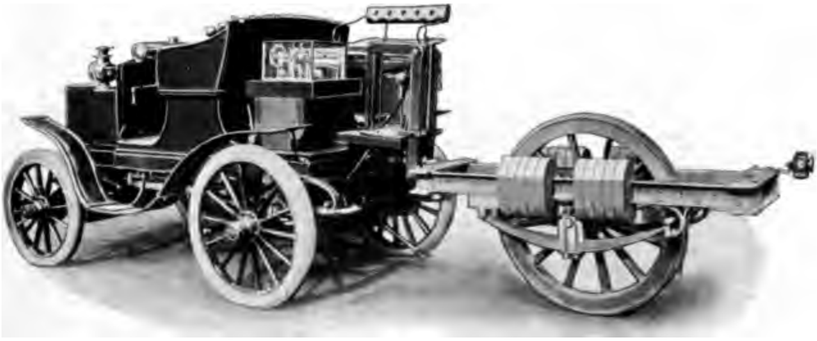
Behaviour of Apparatus.

The behaviour of the apparatus is, on the whole, very satisfactory. The experimental wheel runs very steadily behind the car, even with heavy loads at high speeds. The lurry wheel, however, runs better on setts than on macadam, oscillating sideways somewhat when passing over the latter at a high speed. The pneumatic-tyred wheel runs exceedingly steady over all roads at all speeds.

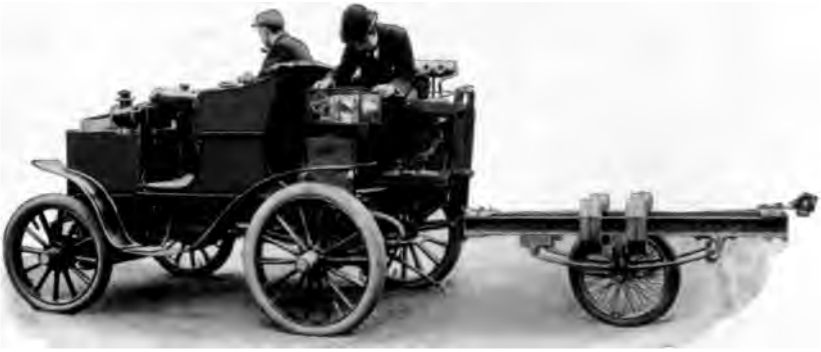
The pneumatic cushion answers very well, allowing the instrument to swing gently from side to side instead of its having to suffer a violent vibration set up owing to the shaking of the car, due both to the engines and to rough roads.

The results given at the meeting were all it was possible to obtain during the short time that the apparatus has been available, but it is hoped that during the ensuing year reliable and valuable results may be obtained, although, of course, to get a complete series of results under all conditions must necessarily involve an immense amount of time and labour, as with so many variable quantities the changes could be rung on them *ad infinitum.*

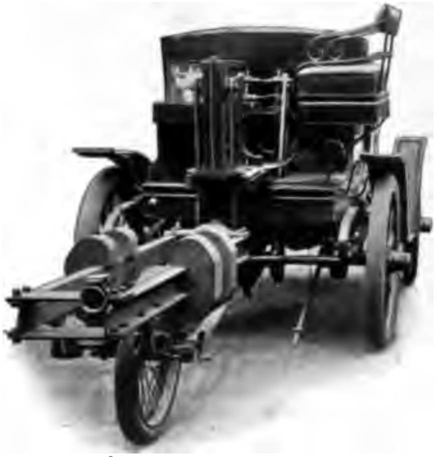
Plate VIII. shows photographs of the dynamometer ready for use; Plate IX. gives views of the recording instrument.



General view of dynamometer, with 40-in. lurry wheel in frame.



General view of dynamometer, with observer in position.
Pneumatic tyre wheel in frame.



Dynamometer. End view from back.

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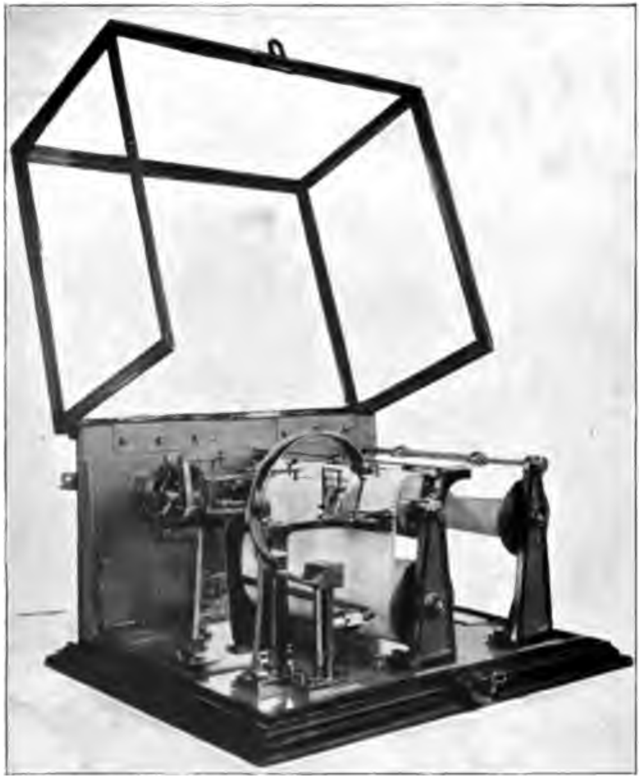
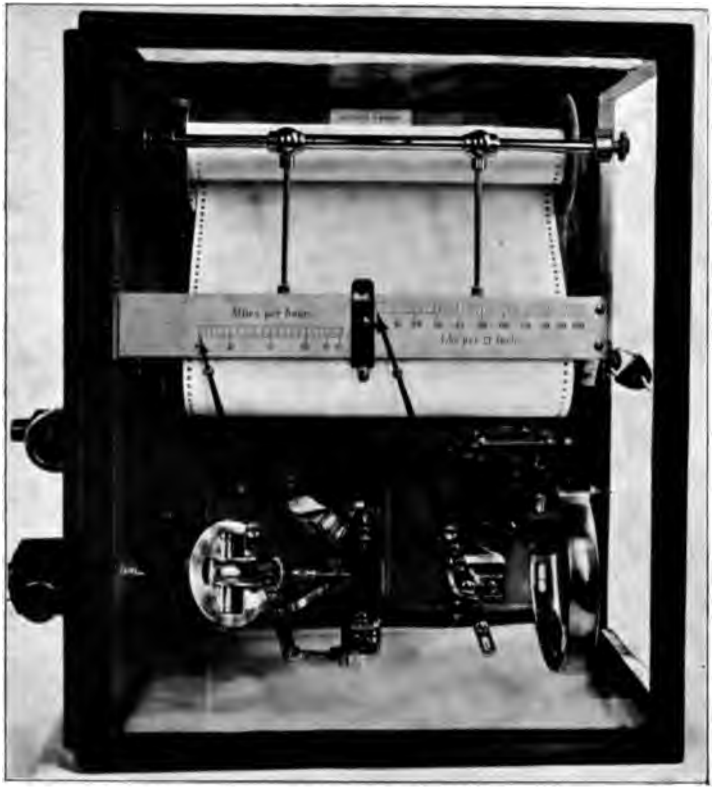


Recording instrument.



View looking down upon recording instrument.

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I. *Results of Trials made with Committee's Dynamometer.*

In the last report the new dynamometer made for the committee was described and illustrated, together with an account of the calibration of the apparatus.

It will have been noticed in the drawing of the instrument that a small screw-down valve was fixed in the circuit of tube which transmits the pressure from the plunger to the recording gauge, this valve being for the purpose of throttling the flow of water, and thus damping the oscillations of the pencil. The principal dimensions of the valve are as follows:—

Width of seat, ...	·008 inch.
Smallest diameter of seat, ...	·1595 ,,
Largest ,, ,, ...	·1693 ,,
Pitch of screw, ...	·046 ,,

It was found that to produce sufficient damping action it was necessary to have this valve off its seat by an amount of not more than ·0153 inch.

It was pointed out by Mr. A. Mallock, F.R.S., of London (a member of this committee), that the flow under a constant pressure of a fluid through a thin film-like orifice such as this, might be different in one direction to what it would be when flowing in a reverse direction, owing to the stream-line formation not being symmetrical about the constriction.

If such were the case the true mean pressure would not be recorded, but some pressure, either greater or less than the true mean, according to which side of the valve was next to the plunger.

Experiments were made to determine the minimum orifice that might be used, and it was found that equal flow from either side did not occur until the valve was opened by at least half a turn, this corresponding to the valve being raised from its seat a distance of ·023 inch. So that there should be no doubt about the orifice being too small, the experiments were conducted with the valve open by a considerable amount, the damping action being obtained by squeezing the rubber tube which connected the gauge to the dynamometer by suitable clips placed on the tube some distance from any change in cross-section. By this means the stream-line flow was kept perfectly symmetrical about the constriction, and hence the true mean pressure was recorded.

Mr. Mallock has suggested the adoption of a length of resistance tubing (say $\frac{1}{60}$th inch bore) to attain the same end, and this will be fitted for subsequent trials.

Experiments.

The first experiments conducted with this dynamometer were mentioned in the last report, and the results were indicated by means of wall-diagrams. The results then obtained have been carefully gone into, and from them the following curves have been plotted.

Experiments with Iron Tyres.

These experiments were conducted on a portion of Regent Road, Bootle, which is paved with setts 6 inches by 3 inches, having a regular but fairly rough surface, with a 1-inch gap between the joints. Regent Road runs along the line of docks, and is in consequence free from gradients; it is, however, so crowded with vehicles during the daytime that it was found necessary to conduct this series of experiments during the night.

The wheel used was a light lurry wheel, 40 inches diameter, having a 3-inch iron tyre slightly rounded in section.

The axle was tilted up out of the horizontal at one end so that the wheel—which was slightly coned—could take up a position exactly similar to the lurry wheels in general use; it was mounted on a pair of springs 3 feet 2 inches between the centres of attachment, each spring comprising six plates 2¼ inches by $\frac{5}{16}$ inch.

Three runs were made over this particular route with loads of 392, 672, and 952 lb. respectively, at speeds of from 5 to 14 miles per hour.

The results of these trials are plotted in fig. 152, with total tractive effort (inclusive of axle friction, etc.), as ordinates, and velocity as abscissæ.

It will be noticed that for each curve the tractive effort increases with the velocity, but these curves and all subsequently obtained are concave downwards, showing that the rate of increase of tractive effort diminishes with the velocity. This may be due to the fact that as the wheel travels faster it has less time to fall into the little hollows in the roadway, merely skimming along the tops of the ridges.

Well-laid setts under these circumstances, even with wide deep gaps, form a perfectly smooth track at high speeds. This is well brought out in fig. 155, which shows a smaller tractive effort for setts than for macadam.

On looking into the matter, this is as it should be. Consider two perfectly level roads, one made with setts and the other with macadam: the setts present a surface which is extremely hard, although irregular, but this irregularity with well-laid setts is more apparent than real, as the tops of the setts themselves are smooth and level and all in the same plane.

The macadam, on the other hand, although quite level, is not nearly so hard as the stone surface, and is, moreover, covered with a thin layer of dust or fine gravel, which, as is well known, retards the progress of a vehicle.

Experiments with Pneumatic Tyres.

A series of experiments were made with a pneumatic-tyred wheel, 24 inches diameter, 2¾-inch tyre. This was a wire-spoked wheel of the type used on light voiturettes; it was mounted on the same springs as the lurry wheel mentioned previously, but they were reduced in strength by the removal of four plates, so that each spring consisted of two plates 3 feet 2 inches long, $2\frac{1}{4}$ inches wide, and $\frac{5}{16}$ inch thick.

This series of experiments was conducted on a level stretch of macadam road, the surface of which was in fairly good condition, slightly wet in places; runs were made with loads of 315, 427, 539, and 651 lb. respectively.

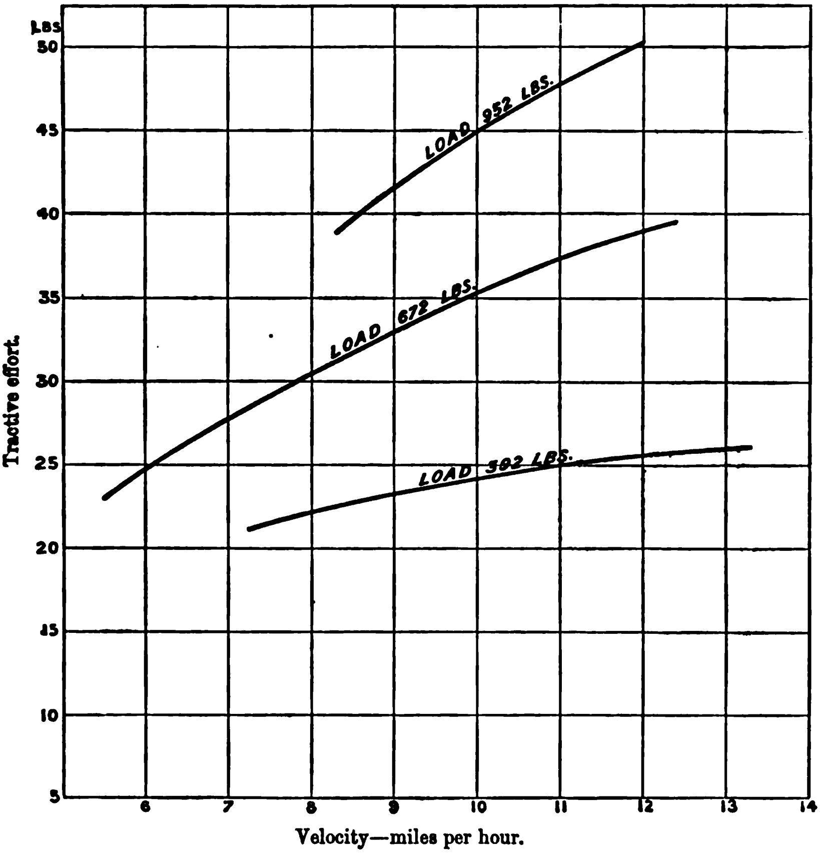


FIG. 152.—Tractive-effort velocity curves for 40-in. iron tyre on setts.

Fig. 153 shows tractive effort and velocity plotted for each of these loads. It will be noticed that the ratio of tractive effort to load for these curves is very nearly constant, and that the tractive effort increases slightly with the velocity. Sufficient results have not yet been obtained to enable this committee to state definitely the law relating to tractive effort and load, but the results of the experiments that have been made agree with those obtained by such pioneers in this research as General Morin, M. Dupuit, M. Michelin, and others. Assuming for the time that

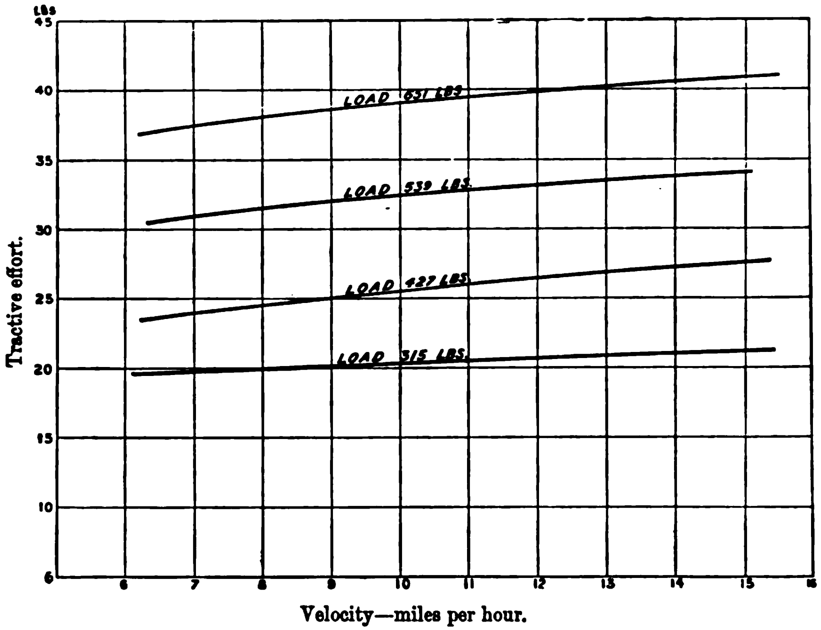


Fig. 153.—Tractive-effort velocity curves for 24-in. × 2¾-in. pneumatic tyre on macadam.

the tractive effort is directly proportional to the load, a curve has been plotted between tractive effort per ton and velocity (fig. 154) which is useful for comparison with similar curves for wheels of different diameters.

Additional experiments were made on pneumatic tyres under the auspices of the Automobile Club of Great Britain and Ireland. For

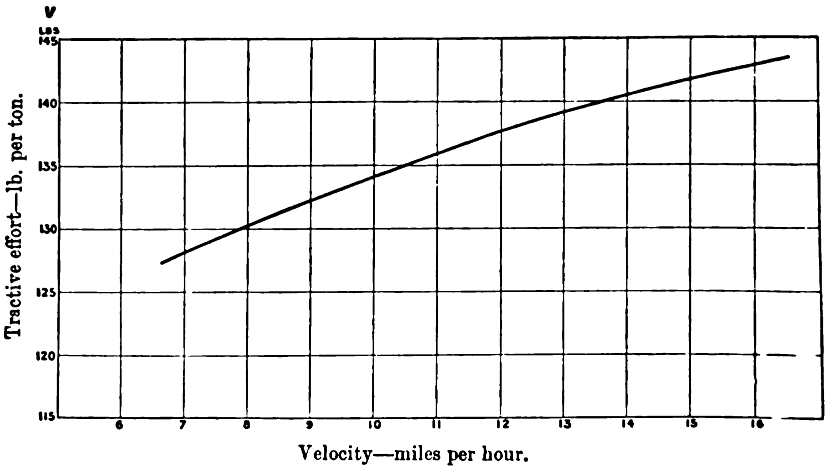
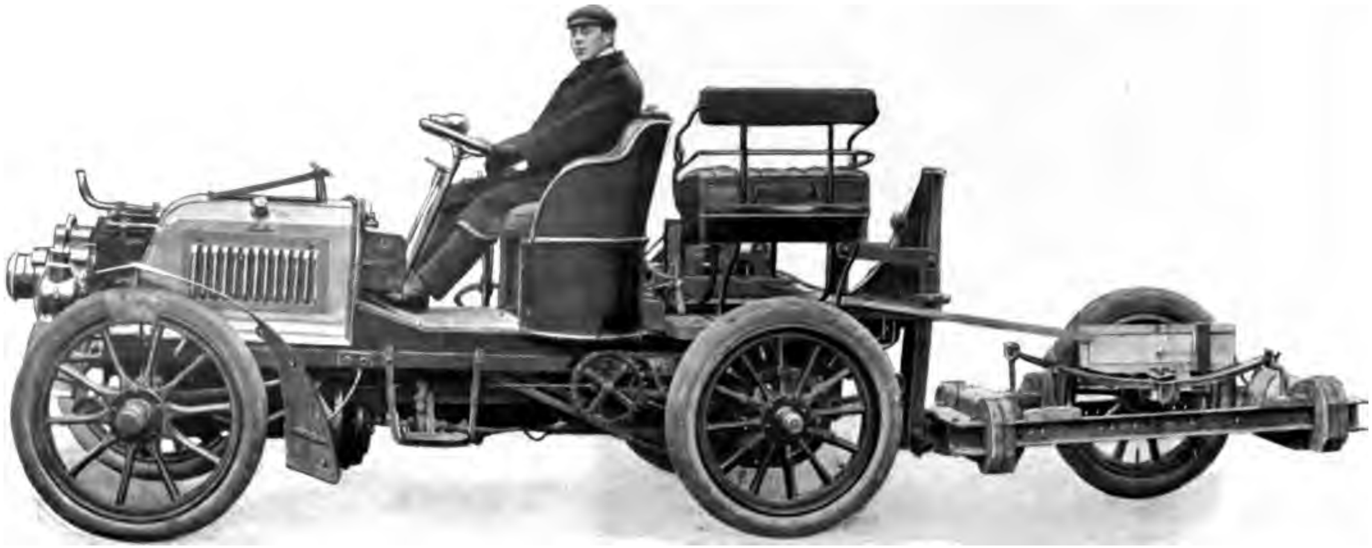


Fig. 154.—Curve showing tractive effort per ton for pneumatic tyre 24-in. × 2¾-in. on macadam.

PLATE X.



Photograph of Panhard and Levassor car, with dynamometer attached.

[*To face p.* 503.

these trials it was found that the car used by the committee was not of sufficient power; a 24 horse-power Panhard and Levassor car was therefore temporarily used.

It will be noticed in the photograph of this later car (Plate X.) that the springs supporting the experimental wheel have been placed above the frame, thus enabling the centre of gravity of the trailer to be brought very near to the ground. This alteration was found necessary owing to a sidelong oscillation taking place at high velocities when the frame was in the position as first arranged. The altered position proved quite successful, not the slightest oscillation of the trailer being noticed even when heavily loaded and travelling at 35 miles per hour, which, it must be admitted, is a fairly high speed at which to tow a wheel loaded with a weight of 900 lb.

Some difficulty was at first experienced in getting this car to pull steadily at lower speeds, as the governor was constantly coming into action owing to the full power not being required. This was finally overcome by completely cutting out two of the cylinders, and thus reducing the power of the car by half.

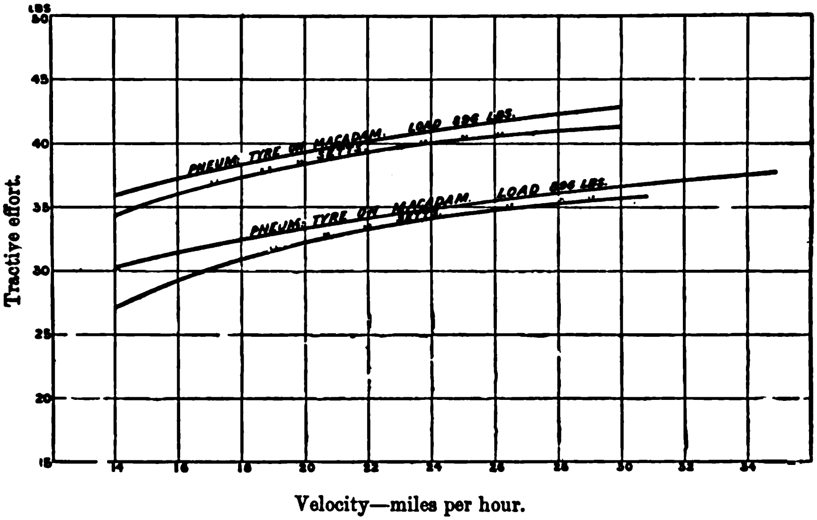


FIG. 155.—Tractive-effort curves for 34-in. pneumatic tyres on new macadam.

These experiments were made with two sizes of tyres, one 34 inches diameter by $3\frac{1}{2}$ inches, and the other 34 inches diameter with a mean diameter of cross-section of $4\frac{1}{2}$ inches.

Runs were made at speeds of from 12 miles to 35 miles per hour, over both good macadam, frozen hard, and good dry setts. The springs supporting the trailer were 3 feet 2 inches long, each having four plates $2\frac{1}{4}$ inches by $\frac{5}{16}$ inch, and the tyres were in all cases pumped to a pressure of 60 lb. per square inch, the total load on the wheel being 896 lb. The results obtained and plotted in fig. 155 show that the tractive effort under similar conditions as to road surface and speed is less for the tyre of smaller cross-section than it is for that having the larger section.

This may be due to the fact that the tread of the larger tyre was much thicker than the smaller, rendering it in consequence more after the nature of a solid tyre, it being well understood that a perfect pneumatic tyre should have as little inelastic, or comparatively inelastic, material about it as possible; or, the greater tractive effort may have been due to the greater cross-section. Repeated experiments alone can definitely settle this question.

Fig. 156 shows these curves plotted as tractive effort per ton. On the same axes the tractive effort per ton has been plotted for the previous wheel (pneumatic tyre 34 inches by 2¾ inches), and it is very much greater than that for the 34-inch wheels.

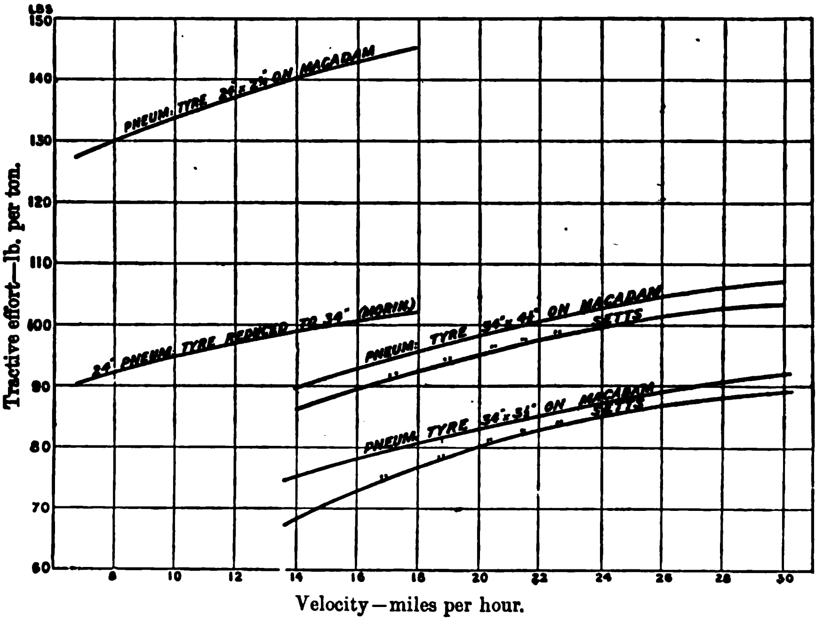


FIG. 156.—Curves showing tractive efforts per ton for pneumatic tyres.

Note.—The macadam on which the 24-in. wheel was run was older than that on which the 34-in. wheels were tried.

This committee is not yet in a position to state the exact relation between tractive effort and diameter of wheel; but, taking the results of General Morin, that the draught is inversely proportional to the diameter of the wheel, a curve has been plotted (fig. 156) which reduces the tractive effort of the 24-inch wheel to that of an equivalent 34-inch wheel. Considering the variations that may have existed in the roads on which the wheels were tried, as it was at different times of the year, these results harmonize fairly well.

II. *Suggestions by Mr. B. J. Diplock.*

The following suggestions with regard to trials of wheels for heavy traffic were submitted to the committee by Mr. B. J. Diplock (member), at a meeting held at the Society of Arts, London, on Friday, May 15, 1903:—

Assuming that:

1. All wheels are coned or straight in cross-section;
2. All roads are arched or flat in cross-section;
3. It seems evident that coned wheels on flat roads, thus—

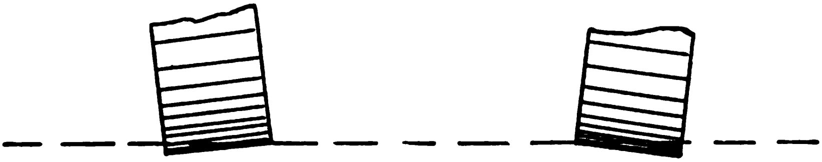


Fig. 157.

or flat wheels on arched roads thus—

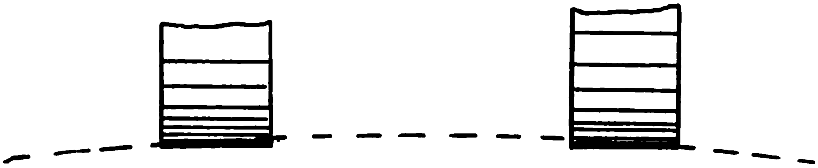


Fig. 158.

cause increased road resistance in proportion as the wheels are coned or the roads arched in relation to each other, and that the same result is caused by inequalities in the road surface—viz., that wide tyres do *not* obtain an even bearing throughout their entire width, except on very soft and yielding ground.

Starting from the above statements, and as the results of long experience and observation, he had come to the conclusion that for *heavy* traffic wheel tyres of *more* than, say, 9 inches in width have, in practice, little or no material value as tending to reduce road resistance or damage to the road surface, and he suggested that experiments might be carried out with a view to testing the accuracy of this conclusion.

Assuming that 9 inches were adopted as a useful maximum width of tyre for heavy haulage on average roads, he submitted the following theory:—

1. That the supporting power of a road is limited by the cohesive friction of the road molecules or particles against each other.

2. That this supporting power limit varies very considerably according to the material used in constructing the road and the moisture absorbed in the road.

He would be prepared to find that road resistance up to certain limits of weight on each wheel (for each class of road) varies approximately in direct proportion to the increased weight on each wheel.

He was of opinion, however, that if this limit of weight per wheel is exceeded so as to overcome the frictional cohesion of the road molecules against each other, then an entirely new set of conditions arises; and he would be prepared to find that road resistance would, under such conditions, increase altogether *out* of proportion to increased weight on the wheels.

He urges that the committee take steps to ascertain—

1. The maximum "useful" width of tyre for *heavy* traffic on average roads.
2. The "limit" of weight on each wheel (for various classes of road) up to which road resistance increases in direct approximate proportion to the increase of weight on each wheel.
3. The rate of increased road resistance when that limit is *moderately* exceeded.

III. *Papers read at the International Congress on Automobilism, Paris*, 1903.

By permission of the British Association Committee a paper was read at the Congress by Professor Hele-Shaw on the work which has been carried out during the past year.

He gave a description of the British Association dynamometer, recounting the reasons why it was decided to adopt the one-wheel trailer, and then gave a *résumé* of the experiments which have been made. The paper was illustrated by photographs and diagrams.

Abstract of Paper by M. Gerard Lavergne, on Tractional Resistance.—Tractive Effort—Springs—Effect of Nature of Tyre—Air Resistance—Power required by Automobiles.

Tractive Effort.

In his paper M. Lavergne referred to the report of this committee read at the Belfast meeting last year, and gave some particulars of similar experiments made in America. He stated that Professor Ira O. Baker, of the Illinois State University, is of opinion that the axle friction is independent of the speed, but varies inversely as the square root of the load supported. Where the vehicles carried only a light load, the coefficient of friction was about 0·02; heavy loads gave an average of not more than 0·015, while with exceptionally heavy loads this coefficient fell as low as 0·012. These values assume efficient lubrication; with indifferent lubrication they rose to as much as six times the amount.

Concerning rolling friction Professor Baker believes that the resistance varies inversely as the square root of the diameter of the wheels.

The values above given for axle friction differ somewhat from those given by M. Forestier, who gives 0·10 for an ordinary bearing lubricated with cart grease, 0·01 with patent axle-box lubricated with oil, 0·005 with lubricated ball-bearings, 0·0025 with the lubricated "Philippe" bearings (which last-named are ball-bearings having small balls between the larger ones, thus obviating friction amongst the latter and ensuring an equal distribution of pressure upon all the balls).

To thoroughly understand the difference between these sets of figures it would be necessary to know the exact conditions of lubrication and the nature of the bearings employed by Professor Baker.

M. Lavergne does not consider that the differences shown are very surprising, as we know that the coefficient mentioned by M. Forestier has reference to a patent journal, the wheel revolving evenly in a plane, without lateral jerks, whilst a wheel revolving in less favourable conditions—as, for instance, on a rough-paved road—would give a higher figure. The most important fact shown by Professor Baker's experiment is that the friction of the journal varies with the load upon the axle.

M. Jeantaud made some experiments on road resistance with an electric vehicle. Such an automobile is eminently suited for this work, on account of the perfect sensibility and absolute accuracy obtainable. He used for these experiments a car having four equal wheels fitted with Michelin tyres 840 by 90 mm.; the front axles were 40·0 mm. diameter, and the back axles were of tempered steel on bronze hubs, the diameter being 55·0 mm. The car with four persons weighed 1780 kilos., or 3925 lb.

At a speed of 15 kilometres per hour, or 9·32 miles per hour, this car required a current of 22 amperes at 80 volts—that is, 1760 watts.

If 15 per cent. is deducted as the friction of the motor itself, the energy of propulsion is 1496·0 watts, or 149·6 kilogrammetres per second.

Working this out in English units, we have a total tractive effort of 81 lb., or 46 lb. per ton.

M. Jeantaud has calculated with Morin's formulæ and coefficients.

First.—The rolling friction, by the formula,

$$F_r = f\frac{P}{D},$$

in which f is a coefficient expressed in kilogrammes, varying with the nature of the road and the width of the tyre, the value of f for a smooth dry road being 0·010; F_r is the rolling friction; P is the total load on the vehicle in tons; and D is the diameter of the wheel.

Second.—The axle friction, by the formula,

$$F_a = s\frac{d}{D}p,$$

in which s is a coefficient expressed in kilogrammes (varying with the mode of lubrication and the nature of the rubbing surfaces) and being taken as equal to 0·015; d is the diameter of the axle; and p the weight of the car without the wheels.

Adding these two resistances and multiplying the total effort by 4·16, the velocity in metres per second corresponding to 15 kilometres per hour, the work done per second is 182·274 kilogrammetres, or 1320 ft. lb.

This figure would be that given for an iron-tyred vehicle, the only kind employed at the time of M. Morin. According to M. Michelin, the advantage obtained by using pneumatic tyres over iron tyres on a road similar to the above would be at least 15 per cent. Taking 15 per cent. off the figure obtained, the work expended on traction is reduced to 154·933 kilogrammetres, or 1120 ft. lb. per second. This value is very near to that actually obtained, viz., 149·6 kilogrammetres per second (1084 ft. lb. per second), and this proves the correctness of the values given for the coefficients f and s.

In January 1903, M. Jeantaud, with the same electric automobile, between the bridges of Bineau and Neuilly, on a stretch of road just 1 kilometre in length, showed that the tractive effort for a road covered with thick mud was, as General Morin found, quite double that on a dry road.

On January 20, on the road in question, being then very muddy, the track was covered on the third speed in 4 minutes, with a current of 30 amperes at 80 volts. In English units this would be a mean speed of 9·32 miles per hour, or 13·66 feet per second, with a total tractive effort of 130 lb., or 74 lb. per ton.

On January 21, over the same kilometre, hardened by the frost and very smooth, on the third speed the track was covered in 3 minutes 28 seconds with a current of 20 amperes at 80 volts. This speed would be equivalent to 10·80 miles per hour, or 15·80 feet per second, with a total tractive effort of 75 lb., or 42·7 lb. per ton.

Thus the tractive effort was 42·3 per cent. less on the hard road than on the muddy road at the third speed. On the fourth speed M. Jeantaud found that this difference increased to 50 per cent.

These experiments confirm those of General Morin, and show the accuracy with which that ingenious man carried out his work. But they have to be made at speeds near to those used by Morin, and it is not at all certain that other experiments, at much higher speeds, under the new conditions of automobilism, so different from those of the iron-tyred vehicles, would give corresponding results.

Springs.

When pneumatic tyres are used, it must not be thought that springs can be dispensed with, as the duty performed by the tyre is quite different from that of the springs. The pneumatic tyre does away with the slight vibration caused by the wheel encountering gravel, stones and small obstacles generally, but the height of the axle from the ground scarcely varies, as the tyre absorbs within itself these small objects.

Experience has proved that these small vibrations, if not absorbed by the tyre, would be transmitted through the springs to the body of the car, to the great discomfort of its occupants, and would tend to reduce the life of the motor, owing to the crystallisation of the parts subjected to strain.

But the pneumatic tyre will not yield much more than 1 inch, and is in consequence unable to save the car from vibration when passing over a large obstacle or a deep rut; whereas the springs, with a resilience of, say, 4 inches, would be well adapted for this purpose.

Spiral springs have been tried with unsatisfactory results, and they can practically only be used where heavy weights are carried. Plate springs must necessarily be employed when ease and comfort are desired.

It may be pointed out here that the method of attaching plate springs to the frame is a matter of considerable importance. M. Gaillardet believes that the usual method is not at all satisfactory. The ordinary practice is to use clips which are pivoted to a bracket depending from the frame, these clips being outside of and lower than the normal plane of the spring. From the bracket they rise at an angle of about 45° and meet the ends of the spring, to which their upper ends are pivoted. The result is, when the wheel passes over an obstruction of any appreciable size, the axle rises under the centre of the spring, the plates of which lengthen (theoretically) and tend to form a straight line, and at once the load above is thrown upward in the same proportion.

On the other hand, where the clips are so connected with the spring as to work within its length and under its ends, instead of beyond them, any shock given to the wheel causes the load to fall, and the loss of mechanical energy is less.

M. Gaillardet is of opinion that the springs should be so arranged that each wheel is free to rise or fall independently of the others. When this is done, an obstacle under one wheel will raise that wheel only, and the centre of gravity of the whole car is raised a smaller distance than would otherwise be the case. To attain this result he proposes to mount the front axle on a single transverse spring, thus reducing the number of springs on the car to three.

When the springs have been depressed by an obstacle in the roadway, they only return to the position of equilibrium after a number of oscillations of decreasing amplitude have taken place. It is advisable to spare the vehicle this continued oscillation, as at high speeds it causes the wheels to leave the ground, and consequently reduces the effective power of the motor. M. Truffault has taken out a patent for an arrangement to remedy this defect. The friction between two metal surfaces prevents the oscillations from arising. He tried a spring fitted with this damping action on a quadricycle, which carried his son to victory over the kilometre at Deauville in 1901. This spring has given very good results, enabling one to travel rapidly even over the worst of paved roads.

Effect of the Nature of the Tyres.

The experiments of M. Michelin have shown that the tractional resistance is reduced from 15 per cent. to 30 per cent., according to the nature of the road, by the use of pneumatic tyres in place of metal tyres. He explains this by the well-known saying, "Le pneu boit l'obstacle." Baron de Mauni, in a recent work, has given an account of some experiments which he made on different tyres, particularly pneumatics. He showed that if two wheels with tyres of equal widths supported equal loads, the one that has the greater arc of contact with the ground will travel better than the other. With a rigid tyre such extended contact can only be secured by increasing the diameter of the wheel, which is impossible beyond certain limits, so that the tyre will sink into the ground by an amount proportional to the weight carried. With rubber tyres the increased area of contact is due to the elasticity of the material and not to the increased diameter, so that the wheel does not sink into the road.

Professor Baker's experiments seem to show that on good roads the width of tyre has little effect on the resistance, and that even on bad roads the advantage lies sometimes with the wide tyres and sometimes with the narrow ones, according to circumstances. Arguments have been advanced in favour of both wide and narrow tyres, but nothing very definite seems to be known on the subject; according to M. Michelin, if we reduce the width of the tyre we reduce the adhesion to the ground, which is already little enough. As a case in point, he mentions that M. Serpollet, in order to attain a speed of 120 kilometres (75 miles) per hour on the Promenade des Anglais in 1902, had to deflate his tyres, and thus get a larger surface of contact with the ground. Besides, in order to get a narrow tread it is necessary to give to the tyre a form other than circular, and this shape can only be retained at the expense of its flexibility. Consequently a tyre of this description will be subjected to greater internal friction in its fabric than one naturally circular in section, and the energy wasted will be therefore greater.

The whole question, however, is very much open to discussion, and the present Congress may offer to the opposing schools an opportunity of coming to some understanding.

Resistance of the Air—Study of Forms to diminish this Resistance.

The air resistance is a retarding force of the highest importance, especially where speed is concerned, and there is unfortunately great uncertainty both as to the formulæ to be applied and the values of the coefficients which appear in them.

The best known formula is

$$R = KSV^2$$

in which R equals resistance in kilogrammes.

S equals projected area in square metres of total surface of vehicle on a plane normal to direction of motion.

V equals velocity in metres per second.

K a numerical coefficient which varies between very wide limits according to the form and the speed of the vehicle.

The formula by M. Desdouits, $R = KV$, is sometimes preferred, as it is more correct for high speeds.

The different values given to K in the first formula may be due to the varied conditions under which the experiments were made.

Signor Canovetti had made some experiments at Zossen to determine the value of K. He had a copper wire, 380 metres long, stretched between the summit of the fortifications at Brescia and a point in the plain, about 70 metres below. Along this wire different surfaces were allowed to descend freely. A circle with a surface of ·073 square metres, moving with a velocity of 12 metres per second, gave a resistance of 84 grammes. The same circle, having a spherical cap in front, offered a resistance of only 21 grammes. When this hemisphere was followed by a cone, whose height was five times its diameter, the resistance fell to 13 grammes, or one-sixth of that of the plane circle. With this same solid, turned the other way about—that is, with the apex of the cone towards the direction of motion—the resistance rose to 18 grammes.

Signor Canovetti has recognised that a rectangular surface, placed with its long sides horizontal, offers a sensibly greater resistance to the air than when its short sides are horizontal. His experiments seem to show that the coefficient K diminishes somewhat as the speed increases, but investigations carried out at Zossen point to the conclusion that the resistance may increase tenfold when the velocity is only tripled. It is thus clear that air resistance is a matter of no small importance when speeds up to 60 or 80 miles an hour are attained. At 85 kilometres (53 miles) per hour, the energy required to overcome the air resistance on a vehicle, with an opposing surface of 1 square metre (1550 square inches), may be 7, 11, or 20 horse-power, according to the coefficient K given as 0·0288, 0·0648, or 0·116 by MM. Forestier, Bourlet, or Thibault.

The question then arises, What is the best shape for a car? The answer depends on several things—as, for example, the necessity of placing the radiator in such a position that it may be efficiently cooled by the air rushing through it. Only general principles may be laid down. The front of the car ought to taper, and the back be more pointed still, like the form of a fish: transverse rectangular surfaces that cannot be dispensed with should, as far as possible, have the longer sides vertical; and it is well to have doors on the car to prevent the air from rushing in between the dashboard and the seat.

These conditions are quite neglected in most of the present-day cars. Particularly is this the case in the "Coffin Head," that unlovely affair so much in vogue—a flat surface directly opposed to the air pressure. With a radiator of the honeycomb type, a transverse position is necessary for cooling purposes, and Signor Canovetti has shown evidence that a perforated surface will offer less resistance to the air than a plane one of similar area. This is not of much advantage with an automobile, as the air, after having passed through the holes in the radiator, meets with further obstacles in the mechanism inside the hood.

With regard to the working parts situated under the car, these should be made by the aid of inclined planes to cut the air rather than oppose it.

M. Lavergne commends the suggestion of M. Forestier that different-shaped bodies should be mounted on an electric chassis, and the total resistance of chassis and body accurately measured, so that a really practical model could be designed.

Power required by Automobiles.

Under this heading M. Lavergne has shown the enormous reduction of weight per horse-power that has taken place during the last eight years. In 1895, Levassor made the run from Paris to Bordeaux in a 4 horse-power car weighing about 1 ton, or 1 horse-power per 550 lb. dead weight. In 1896 this weight was reduced to 365 lb. per horse-power; in 1900 it fell to 90 lb. per horse-power. In the recent Paris-Madrid race, M. Gobron Brillie appeared with a 100 horse-power car, the weight of which represented only 22 lb. per horse-power. This weight has been still further reduced in the case of motor bicycles, reaching as low a figure as 17·5 lb. per horse-power.

But there is not a corresponding increase in speed. In 1901 M. Fournier made over 53 miles per hour with a 28 horse-power Mors; last year M. de Knyff only slightly exceeded 58½ miles per hour with a 70 horse-power motor—that is, an additional 40 horse-power.

To what must this relatively small increase of speed be attributed? Air resistance is responsible for some increase, but certainly not all.

An extremely powerful motor must be accompanied by a comparatively heavy load, otherwise the wheels do not "bite" well and energy is wasted. It is well known that the modern racing-car skims along the surface of the course, without sufficiently close contact between the wheels and the ground; in any case driving wheels should be more heavily weighted and springs made less elastic. To reduce the power lost in vibration, the engine should be more perfectly balanced, and, if necessary, the fly-wheel and motor itself made heavier. "Who shall say," M. Lavergne concludes, "whether, instead of building very powerful yet extremely light motors—

the durability of which is questionable—it would not be better to rest content with a vehicle of smaller power, and use it more effectively?"

IV. *Negotiations with the War Office.*

At a committee meeting held at the Society of Arts on May 15, 1903, it was proposed that as the expenses of this research were extremely heavy, it would be advisable to approach the Mechanical Transport Committee of the War Office, in order to see if they would conduct the experiments with heavy traction, as they had at their command various powerful motors and traction engines, together with the necessary variety of wheels. The Transport Committee in return would have the use of the British Association recording instruments for their own experiments.

This British Association Committee would have access to the information obtained which was of a scientific character, with a view to publication, but it would not concern itself with data relating to the actual wagons and other matters of a purely military character.

As a result the Transport Committee replied favourably, and arrangements, it is hoped, will now be made by which important work will be carried on by that committee, thereby avoiding the very heavy expense to meet which it is difficult to raise funds from private sources.

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